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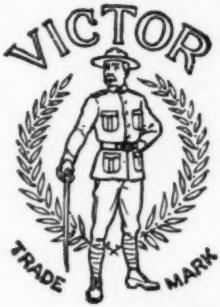

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THE TRANSACTIONS OF THE SOCIETY, INCLUDING THOSE FOR 1906, WILL APPEAR IN THE *Journal*

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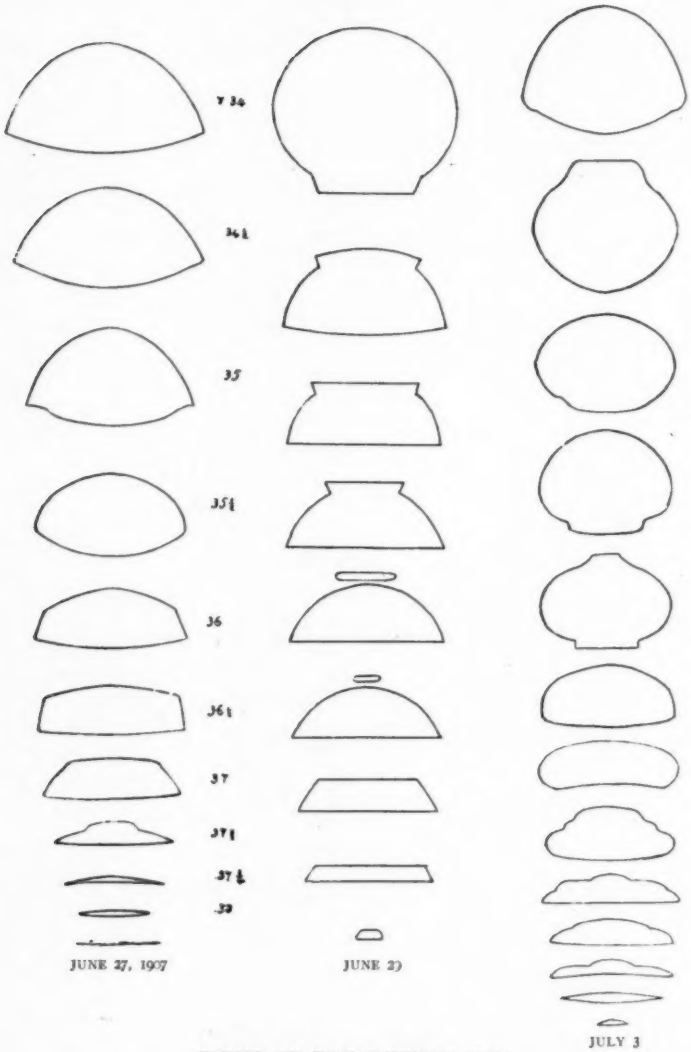

FORMS OF THE SETTING SUN
AS SEEN FROM THE SUMMIT OF MOUNT HAMILTON, CAL.

(See page 324)

THE JOURNAL
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OF CANADA

VOL. I. SEPTEMBER-OCTOBER, 1907. NO. 5.

THE ASTRONOMY OF SHAKESPEARE.

BY JOHN A. PATERSON.

FRANCIS Bacon has given us a most beautiful exposition of the fable of the Sphinx, that monster of classical myth who dwelt on the top of a mountain near Thrace and propounded certain dark and perplexing riddles to travellers whom she captured. If these luckless ones did not solve her riddles, she fell upon them in their hesitancy and confusion, and tore them in pieces. The Thebans offered the kingdom to whomsoever would answer her riddle and destroy the monster. Œdipus, a wise and penetrating man though lame in his feet, ambitious for so great a reward, undertook the task at the risk of his life, and presented himself to the Sphinx for the trial. He interpreted the puzzle propounded, slew the monster, and laying the carcase upon an ass, led her away in triumph and became by agreement king of Thebes. This fable, says Bacon, represents Science, for she is a monster elevated on a height, strangely gazed at and admired by the ignorant and unskilful. If the problems of Science remain unsolved, then the result is doubt, and minds racked and torn by despair ; if solved, then knowledge is power and empire comes to those who unlock the mystery and reveal the truth. The lame man conquers because men who make

haste to search the secrets of Science fail in their quest, but, on the contrary, men who approach the problems slowly and cautiously in the end overcome. When the Sphinx was conquered her carcase was laid upon an ass, which signifies that there is nothing so subtle or abstruse but when made plain by some one master mind becomes intelligible and clear, and is accepted by the lowest capacity.

Thus it is that Science slowly struggles and painfully plods, and yet surely and strongly makes her advances farther and farther into the continent of Time, which ever opens onwards. The old Ptolemaic cosmogony with this little earth of ours in the centre of the universe and its laborious mechanism of spheres and cycles and epicycles, died hard,—while Copernicus, Galileo and Kepler toiled painfully and sadly to shed the light of truth over a dark and troublous ocean of error. As Tennyson puts it,

> "Science moves, but slowly, slowly, creeping on from point to point;
> Slowly comes a hungry people"—

that is, as I understand it, a people hungry for truth. Milton (as I showed upon a previous occasion) who wrote his *Paradise Lost* between 1653 and 1658, lived in an age so saturated with the old Ptolemaic astronomy that he constructed his poem according to that theory, although it is clearly indicated in the eighth book that his own intelligence rebelled, and that he was an unwilling but honest convert to the heliocentric theory. Copernicus propounded his new system in the year of his death, A.D. 1543, and Milton, one of the most cultivated scholars of his time, more than a hundred years after, was not very certain as to whether Copernicus was right or not, even although he had in his early years travelled in Italy and conversed with Galileo, "the Tuscan artist" with his "optic tube." Nay more, this same Milton taught the Ptolemaic or Alphonsine system from that most veracious scientific treatise *De Sphera Mundi*, which was for four hundred years the school text-book for astronomy. Can you imagine any school or college now teaching any branch of science from a book four hundred years old, or even forty years old?

The angel Raphael is very curiously made by Milton to give our great ancestor, Adam, some advice which runs thus :—

> "This to attain whether Heaven move or earth
> Imports not if thou reckon right: the rest
> From man or angel the great Architect
> Did wisely to conceal and not divulge
> His secrets, to be scanned by those who ought
> Rather admire."

And again :—

> "Solicit not thy thoughts with matters hid:
> Leave them to God alone: him serve and fear."

In this Milton meant to teach reverence, but he certainly taught a bad philosophy. It is the duty of every man to solicit his thoughts with matters hid. God surely never intended them to be left to him alone, and we serve him most worthily and fear him most when we seek to solve his secrets and thus to rise from Nature up to Nature's God.

If it was thus with Milton in 1663, what are we to expect in Shakespeare, who wrote his poems and dramas between 1591 and 1608, only about half a century after Copernicus had promulgated his theory, and about the same time as Galileo was speaking? Bacon died in 1626, long after Copernicus had taught and sixteen years after he had been heard from. Kepler had published his discoveries in 1609, but there were no scientific journals in those times to scatter the sunlight of truth throughout the nations, and Science still sat on a height panoplied like a Gorgon and shrouded like some hydra-headed monster, so that even this Francis Bacon, this prince of philosophers, "the wisest, brightest, meanest of mankind," had not yet approached her pedestal. In *Thema Cœli* he speaks after this fashion: "It is the absurdity of these opinions that has driven men to the diurnal motion of the earth which I am convinced is most false": and in another passage he alludes scornfully to "those few carmen which drive the earth about." Copernicus he calls "a man who thinks nothing of introducing fictions of any kind into nature provided his calculations turn out well." But light came,

though slowly, for we find him later in life doubting both theories and favoring a sort of balance between them. "It is easy to see," he says, "that both they who think the earth revolves and they who hold the *primum mobile* and the old construction are about equally and indifferently supported by the phenomena." A man who has no opinions at all, but who desires to reach the truth, is in a better condition than one whose mind is occupied and fortified by the demons of error and darkness. Scientific truth does not spring at once full-statured and completely armed as Minerva from the brain of Jupiter; its germ may lie dormant while the iron yoke of conformity to the false theories of the age sets heavily on our necks. Habit is as great a tyrant over our minds as it is over our bodies, and what is called education is sometimes no more than the dull repetition of old formularies and safe platitudes. The Sphinx is left alone on her rocky height, and she utters her riddles to the winds. No bold adventurer is rent in pieces, nor any wise, slow-moving Œdipus approaches her and listens to her questions. It has thus been put—

> "We think so because all other people think so;
> Or because—or because—after all, we do think so;
> Or because we were told so, and think we must think so;
> Or because we once thought so and think we still think so;
> Or because, having thought so, we think we will think so."

In the Herveian Oration delivered by Dr. Wm. Osler before the Royal College of Physicians and Surgeons on the 18th of October, 1905, there occurs a quotation from Sir Wm. Temple, the statesman and author, who lived between 1628 and 1699. Speaking of Harvey (the discoverer of the circulation of the blood) and Copernicus, those rude knight errants who stirred up dry bones, and had a disagreeable and undaunted way of propounding new theories and proving them true, Sir Wm Temple, about a hundred and twenty years after Copernicus had published his solution of the Sphinx problem, says: "Whether either of these be modern discoveries or derived from old foundations is disputed; nay, it is so too whether they be true or no; for

though reason may seem to favour them more than the contrary opinions, yet sense can hardly allow them, and to satisfy mankind both these must concur. But if they are true, yet these two great discoveries have made no change in the conclusions of Astronomy nor in the practice of Physic, and so have been but little use to the world though perhaps of much honour to the authors." There are birth pangs in the intellectual world when a new idea is brought forth, and often too at such a time the dogs of war are let loose. As Truth personified once said, "I have not come to send peace on earth but a sword." In whatever form truth comes, scientific, moral, or spiritual, the hour of its birth is the hour of battle.

If, then, Milton, who wrote sixty years later than Shakespeare, had such a dim apprehension of the new astronomy, what knowledge shall we expect Shakespeare to have? If Milton, the distinguished Cambridge savant, the travelled gentleman, the sagacious statesman, the embodiment of diversified knowledge, viewed the sun-centre philosophy as doubtful, what appreciation of it shall we look for in Shakespeare? If Bacon, the most accomplished scholar of his day and the philosopher whose chief purpose was to foster the spirit of free inquiry and advance the study of physical science, did not accept the Copernican hypothesis, what must we expect from the actor and play-wright of grammar-school education? We cannot look to find much astronomical fertility in Shakespearian soil; for neither the learning of his day, nor his own training and pursuits, nor the literary subjects with which he dealt, lend themselves to any astronomical research. With Milton the very theme of *Paradise Lost* forced some cosmogonical theories before the readers, and modern poets, too, like Tennyson, who have lived in an age of great and rapid scientific progress when every discovery is blazoned abroad by newspaper and magazine, are naturally concerned in some degree with the speculations of the astronomer. Our poet sets it down that in Hamlet's day "the toe of the peasant comes so close to the heel of the courtier." That is even more applicable to the conditions of our democratic times, but it

is equally true that the toe of the everyday man touches the heel of the scientific discoverer. And because science has entered more into the heads and hearts and homes of the people, there are in the poets of the latter half of the last century more lessons in science than in all the poets in previous centuries combined.

Shakespeare wrote a little before the great scientific revival. He taught no science, but he took oftentimes what he found ready to hand among the common people and touched it with poetic radiance. His cosmogony was that of Pythagoras. The earth was the centre of all things and to it the planets and stars were tributary, to it they made obeisance, as the sun and the moon and the eleven stars made obeisance to the Hebrew Joseph in his dream. The darkness of superstition still lingered over England. The astrologer was abroad; he calculated nativities, cast horoscopes and turned the world upside down to suit his customers. And this was not confined to the common people, but even so eminent a scholar as Kepler believed in astrology—for indeed we may say that Kepler was an immortal without a living: the discovery of his three great laws (the forerunners of Newton's discovery of universal gravitation) made him immortal, while astrology gave him a living.

To understand fully the astronomy of Shakespeare, let us shortly set forth the basis of the system of Pythagoras. The Londoners who went home from the Globe Theatre after the play saw above them in imagination, ten huge, rigid, transparent spheres or shells revolving about them, and firmly fixed in each of seven of these spheres a planet,—the Moon, Venus, Mercury, Sun, Mars, Jupiter, and Saturn; above these the sphere of fixed stars; then a crystalline sphere; and beyond the other nine the *primum mobile* or sphere of first motion as viewed from the outside, and carrying all with it from east to west. Beyond all was the immovable empyrean, where God and the angels dwelt and furnished the motive force for the whole complex machinery of globes. Each sphere not only moved with a velocity different from that of the others, but was turned by an angel, and the soft sliding of the hollow shells over each other produced a heavenly

strain of music. Hence Lorenzo's words to Jessica as they sit in the garden at Belmont and look at the "floor of heaven":—

> "There's not the smallest orb which thou beholdest,
> But in his motion like an angel sings,
> Still quiring to the young eyed cherubims.
> Such harmony is in immortal souls;
> But whilst this muddy vesture of decay
> Dost grossly close us in, we cannot hear it."

And again in *Twelfth Night* Olivia says to Viola

> "But would you undertake another suit;
> I had rather you to solicit that
> Than music from the spheres." (III, 1).

Thus our forefathers brought the stars and planets into direct contact with the supernatural, and the result was a tendency to preserve that simple religious reverence which is far from being a characteristic of our age. Doubtless we have more scientific truth nowadays, and truth ought to make us not only more strong but also more devout and humble, but while dragging the Sphinx from her pedestal are we not losing something of pious allegiance to the supernatural?

When we know that such eminent men as Roger Bacon, Lord Bacon, Usher, Lilly, Milton, Bishop Hall and Sir Matthew Hale credited the pretensions of astrology, what wonder is it that Shakespeare was under its thrall? In *Twelfth Night* Sebastian says—

> "My stars shine darkly over me."

Romeo defies the stars, and Kent declares "It is the stars, the stars above us as govern our condition." In *Troilus and Cressida* Thersites says of Diomede—"When he performs, astronomers foretell it." In regard to the practice of casting figures from the appearance of the heavens at birth we have several allusions. In *As You Like It* Rosalind says to the melancholy Jacques—"Be out of love with your nativity and almost chide God for making you that countenance that you are." Glendower in a swaggering vein boasts that at his nativity

"The front of heaven was full of fiery shapes
Of burning crossets, and at my birth
The frame and huge foundation of the earth
Shaked like a coward."— (III. 1).

appealing not only to astronomy but even to the unborn science of seismology. The crook-backed Richard thus sneers about the murdered princes—

"At their births good stars were opposite." (IV. 4).

From some passages, however, it would almost appear that Shakespeare had little faith in astrology, but only echoed the vulgar beliefs of his day. In *Sonnet XIV* he writes

"Not from the stars do I my judgment pluck;
And yet methinks I have astronomy,
But not to tell of good or evil luck
Of plagues or dearths or seasons' quality."

And again Cassius says to Brutus

"The fault, dear Brutus, is not in our stars,
But in ourselves, that we are underlings. (*Jul. Cæs.* I. 2).

"Our remedies oft in ourselves do lie
Which we ascribe to Heaven: the fated sky
Gives us free scope; only, doth backward pull
Our slow designs, when we ourselves are dull."
(*All's Well that Ends Well* I. 1).

In *King Lear* Edmund ridicules astrology with some vehemence—"This is the excellent foppery of the world that when we are sick in fortune—often the surfeit of our own behavior—we make guilty of our disasters the Sun, the Moon and the stars, as if we were villains by necessity; fools by heavenly compulsion; knaves, thieves and traitors by spherical predominance; drunkards, liars and adulterers by an enforced obedience of planetary influence." This sounds like the most thorough-going skepticism, but it need not represent Shakespeare's own views on the subject of astrology any more than the speeches of Iago or Gloucester embody his philosophy of life.

Although the Ptolemaic astronomy had its own explanation of eclipses, yet astrology had much to say about them and could

speak the more fluently because not "cabined, cribbed, and confined" by the mathematics of cycles and epicycles. In *King Lear* we have a complete epitome of the astrological doctrine of eclipses :—"These late eclipses in the Sun and Moon portend no good to us. Though the wisdom of nature can reason it thus and thus, yet nature finds itself scourged by the sequent effects ; love cools, friendship falls off, brothers divide ; in cities mutinies ; in countries discord ; in palaces treason ; and the bond cracked 'twixt son and father." Shakespeare is constant in his references to the influence of the planets on mundane affairs. Kent in *King Lear* explains the difference between the gentle Cordelia and her venomous sisters in this wise

> "It is the stars,
> The stars above us govern our conditions;
> Else one self mate and mate could not beget
> Such different issues." (IV. 3).

Allusions to the planetary influence on character are of frequent occurrence. Mercury was a thief and the god of thieves. Indeed once he had tried to filch the very thunderbolts of Jove himself ; but they proved too hot and too heavy—and electric cranes were not yet known. In *Winter's Tale* Autolycus thus soliloquizes—"My father named me Autolycus; who, being as I am, littered under Mercury, was likewise a snapper-up of unconsidered trifles." (IV. 3). Those born when Mars was in the ascendant were according to the astrologers quarrelsome and querulous, full of boasting and braggadacio. Thus in *All's Well That Ends Well*—

"*Helena.* Monsieur Parolles, you were born under a charitable star.

Parolles. Under Mars, I.

Helena. I especially think, under Mars.

Parolles. Why under Mars?

Helena. The wars have so kept you under, that you must needs be born under Mars.

Parolles. When he was predominant.

Helena. When he was retrograde, I think, rather.

Parolles. Why think you so?

Helena. You go so much backward, when you fight." (I. 1).

Note the satirical turn given to the astrological terms "predominant" and "retrograde."

According to Ptolemy, Saturn, which revolves in the far away seventh sphere, a cold and cheerless region, is the planet of old age, and Venus near the Sun is the planet of love. Hence comes Prince Henry's witticism when he surprises Falstaff flirting with Doll Tearsheet—"Saturn and Venus this year in conjunction! What says the almanac to that?" (*2 H. IV.* II. 4). Jupiter is mentioned in *Cymbeline*

> "Our Jovial star reigned at his birth and in
> Our temple was he married." (V. 4).

Each planet has its perfection and its corresponding influence. When Shakespeare wishes to unite excellences, to pile Pelion on Ossa, he calls in most beautifully the doctrines of astrology. Antiochus thus praises the virtues of his daughter—

> "The senate-house of planets all did sit,
> To knit in her their best perfections." (*Per.* I. 1).

Leaving for the present further astrological allusions, let me now point out some passages that teach the Ptolemaic doctrine of the universe. In a passage in *Troilus and Cressida* we have this interesting summary:—

> "The heavens themselves, the planets, and this centre
> Observe degree, priority, and place,
> Insisture, course, proportion, season, form,
> Office and custom, in all line of order;
> And therefore is the glorious planet Sol
> In noble eminence enthroned and sphered
> Amidst the ether; whose medicinable eye
> Corrects the ill aspects of planets evil
> And posts like the commandment of a king
> Sans check to good and bad."

Here "this centre" is, of course, the Earth. Observe that the Sun is called a planet; it occupied the fourth sphere according to the Ptolemaic system. Note also the expression applied to the Sun—"whose medicinable eye." In a narrow sense this may be merely an astrological term signifying that the Sun counteracts the evil effects of ordinary planets, but I think we

may strike a higher note and give it a wider and more pregnant meaning. Shakespeare indeed built better than he knew, for he was in this our contemporary in science, because here in a word is the germ of the modern science of solar physics. The Sun is the source of all life and growth and motion in the world, the master-therapeutic before whom the minute organisms of disease shrivel and die. Shakespeare adds "And posts like the commandment of a king." Ptolemy did not know how great a king the Sun was, but Shakespeare with a sort of unconscious prophetic vision stumbled on the truth. The Sun like a king "in noble eminence enthroned" rules the Earth and planets. Like an admiral he guides his fleet unerringly over the azure ocean of space; his despatches go forth swifter than the wings of light, and each planet, satellite, comet, and meteor turns in his course at the appointed place and time, and circles round his fiery throne. The Earth and her sister planets are indissolubly bound to this monarch by the mysterious force of gravity, and they follow him so loyally and faithfully as to match that splendid expression of devotion set forth in the Hebrew poem. As Ruth to Naomi, so each planet to the Sun—"Entreat me not to leave thee or to return from following after thee, for whither thou goest I will go; and where thou lodgest I will lodge; where thou diest I will die, and there will I be buried." Such a parallel suggests the possible cataclysm of nature to which Shakespeare makes eloquent reference.:—

> "And like the baseless fabric of this vision,
> The cloud-capped towers, the gorgeous palaces,
> The solemn temples, the great globe itself,
> Yea, all which it inherit, shall dissolve
> And, like this unsubstantial pageant faded,
> Leave not a rack behind." (*Tempest*, IV. 1).

This quotation brings us to notice that Shakespeare here and elsewhere refers to the sphericity of the Earth—

> "We the globe can compass round
> Swifter than the wandering moon."
> (*Mid. Night's Dream*, IV. 1).

And again King Lear in his noble rage thus cries

> "And thou all-shaking thunder
> Smite flat the thick rotundity of the world." (III. 2).

And Puck leaves us breathless with his exclamation—"I'll put a girdle round the earth in forty minutes." Doubtless the theatre-goers of that day laughed at this as a pretty piece of extravagance, but nowadays the circuit of the world can be actually and not poetically completed in less than no time. Once again in this same play Hermia speaks of the possibility that the whole Earth might be bored and the moonlight "through the centre creep, and so displease her brother's noontide with the Antipodes." (III. 2).

Newton discovered the law of gravitation seventy years after the death of Shakespeare, but before his day there were many foreshadowings and suggestions of the attraction of the Earth. In *Troilus and Cressida* we have:—

> "But the strong base and building of my love
> Is as the very centre of the earth
> Drawing all things to it." (IV. 2).

This is all that Shakespeare knew in regard to the nature of this mysterious force and it is all that we know about it. We have learned to refer it not to the Earth alone but to all matter and we know its law mathematically, but the real meaning, the essence, what it is, and whence and why, we can no more explain than Shakespeare or Ptolemy. In another passage of the same play we have "As true as iron to adamant, as earth to centre," meaning that every particle is drawn to the Earth like a central magnet.

The astrology of the Almagest put England under the dominance of Mars in Aries—whence the force of John of Gaunt's words—

> "This royal throne of kings, this sceptred isle
> This earth of majesty, this seat of Mars." (*Rich. II.* II. 1).

If Shakespeare did not know astronomy as we know, he assuredly made a splendidly patriotic and glowingly poetic use of the knowledge he had. After all it is not how much knowledge we

possess that is the important matter, but how we employ our knowledge. And before we leave the subject of Mars, let us not forget that Shakespeare was not only a poet, but that he was also an observer of the motions of Mars the planet.

* * * * *

It would be strange if Shakespeare were silent about the Moon. To her he has many allusions. In *Midsummer Night's Dream* Titania speaks—

> "Therefore the moon, the governess of floods,
> Pale in her anger, washes all the air." (II. 2).

The floods referred to are doubtless those of the ocean, but perhaps also atmospheric currents which bring down the rain—whence the phrase "washes all the air." And again in *Winter's Tale*

> "You may as well
> Forbid the sea for to obey the moon,
> As by oath remove or counsel shake
> The fabric of his folly." (I. 2).

We find even Falstaff and the heir apparent to the British throne discussing the tidal theory, giving to it, however, some socialistic significance. Listen to Sir John as he wheezes and puffs and rumbles out—"Let us be Diana's foresters, gentlemen of the shade, minions of the moon, and let men say we be men of good government, being governed as the sea is by our noble and chaste mistress, the Moon, under whose countenance we steal." To whom Prince Henry—"Thou say'st well and it holds well too; for the fortune of us that are the Moon's men doth ebb and flow like the sea, being governed, as the sea is, by the Moon." Shakespeare also knew that the Moon shone by reflected sunlight. In *Timon of Athens* we find—

> "The moon's an arrant thief,
> And her pale fire she snatches from the sun." (IV. 3).

And again in the same play—

> "*Alcibiades.* How came the noble Timon to this change?
> *Timon.* As the moon does, by wanting life to give:
> But then renew I could not, like the moon;
> There were no suns to borrow of," (IV. 3).

Thersites denounces the treachery of Diomede with true Homeric frankness and bitterness—"That same Diomed's a false-hearted rogue, a most unjust knave . . . The sun borrows of the moon when Diomed keeps his word."

* * * * *

The phenomenon of the changes in the Moon is most beautifully employed by Shakespeare in one of the tender passages of *Romeo and Juliet*:—

"*Romeo.* Lady, by yonder blessed moon I swear
That tips with silver all these fruit-tree tops.
Juliet. O swear not by the moon, the inconstant moon
That monthly changes in her circled orb,
Lest that thy love prove likewise variable.
Romeo. What shall I swear by?
Juliet. Do not swear at all;
Or, if thou wilt, swear by thy gracious self,
Which is the god of my idolatry,
And I'll believe thee." (II. 2).

In all the ages lovers have in their fire sworn by the Moon, and thereafter have in their calmness foresworn themselves. Shakespeare also recognized the well-known fact that the moonlight has a ripening effect upon vegetation as is shown in *Troilus and Cressida*

"As true as steel, as plantage to the moon,
As sun to day, as turtle to her mate." (III. 1).

* * * * *

The almanac man was abroad in Shakespeare's day—not the almanac of science, not the nautical almanac (for Dr. Maskeleyne was not) but the almanac of astrology with its unblushing shamelessness and fertility of prophecy interspersed with some scientific notes collated from the experience of the ages. Thus in *Midsummer Night's Dream* when the clowns are preparing their little drama, we find this dialogue:—

"*Snout.* Doth the moon shine that night we play our play?

Bottom. A calendar, a calendar! Look in the almanac, find out moonshine, find out moonshine.

Quince. Yes, it doth shine that night." (III. 1).

But we must leave the Moon and for an instant we pause to note a passage in *Timon of Athens*, where the lifting force of the Sun by its evaporation of the sea is recognized :—

> "The sun's a thief and with his great attraction
> Robs the vast sea." (IV. 3).

The phenomena of parhelia or mock suns or sun-dogs, and mock moons are recognized by Shakespeare, which foreboded good or evil according to the necessities of some political situation or the will of the astrologer. These strange appearances were looked upon with awe and ignorant wonder, and having no scientific explanation were celestial prophecies. Edward of York, the son of Plantagenet, sees in the sky his future sovereignty as Edward IV.

> "*Edward.* Dazzle mine eyes or do I see three suns?
> *Richmond.* Three glorious suns, each one a perfect sun,
> Not separated with the racking clouds,
> But severed in a pale clear shining sky.
> See, see! they join, embrace and seem to kiss,
> As if they vowed some league inviolable;
> Now are they but one lamp, one light, one sun;
> In this the heaven figures some event."
> (3 *Hen. VI*, II. 1).

In the night sky a phenomenon of mock moons presages evil to King John—

> "My Lord, they say five moons were seen tonight,
> Four fixed, and the fifth did whirl about
> The other four in wondrous motion." (IV. 2. 182).

The whirling about is no doubt a coinage of the brain, an ecstacy of the imagination. The astronomical explanation does not account for the "wondrous motion," but only for more moons than one.

On the Ides of March, the 15th of March, a few days before the vernal equinox, when the Sun is a degree or more south of the equator, the day when Julius Cæsar bled, Shakespeare with wonderful accuracy puts these words in Casca's mouth :—

"Here as I point my sword, the sun arises,
Which is a great way growing on the south,
Weighing the youthful season of the year.
Some two months hence, up higher toward the north
He first presents his fire; and the high east
Stands, as the Capitol, directly here." (II. 1).

"A great way growing on the south" meaning that the Sun had almost finished its course south of the equator and was approaching the equator: "Weighing the youthful season of the year" meaning that the Sun was in the spring season, and balancing or dividing its course by reaching the equinoctial. The poet must have been a close observer of the skies.

References to the stars in our author's works are so numerous that we can make mention of only a few. The North Star and its immovability is often spoken of. In *Othello* we have this vigorous description of a storm at sea:—

"The wind-shaked surge with high and monstrous mane
Seems to cast water on the burning Bear,
And quench the guards of the ever fixed pole." (II. 1).

And again when Cassius presses Cæsar to repeal the banishment of Publius Cimber, proud of his inflexibility, the emperor makes the famous comparison:—

"I am constant as the northern star,
Of whose true fixed and resting quality
There is no fellow in the firmament.
The skies are painted with unnumbered sparks;
They all are fire and every one doth shine;
But there's but one in all doth hold his place:
So in the world—'tis furnished well with men,
And men are flesh and blood and apprehensive;
Yet in the number I do know but one
That unassailable holds on his rank,
Unshaked of motion." (III. 1).

The movement of the heavens round the pole is also described in *Hamlet*:—

"When yon same star, that's westward from the pole,
Had made his course to illume that part of heaven
Where now it burns." (I. 1).

The Great Bear is mentioned as Charles's Wain and also as Ursa Major. He is not only a member of a sidereal menagerie, but also a sidereal clock. In the first part of *Henry IV* we have—"Charles's Wain is over the new chimney and yet our horse not packed."

The Pleiades are not forgotten by our author. Falstaff is his observer, for while the "greasy knight" wears mostly the cap and bells, yet he on occasion can play the astronomer: for example—"Indeed, you come near me, now, Hal: for we, that take purses, go by the moon and the seven stars; and not by Phœbus." (I. *Henry IV.* I. 2). And the fool in *Lear* drops into astronomy in this wise—"The reason why the seven stars are no more than seven is a pretty reason." (I. 5). It would be strange if in an age of astrology and superstition we found no references to comets, those fearful harbingers of disaster. We have space for only one allusion. The faithful wife of Cæsar tries to keep him from the senate house on that fateful day:—

> "When beggars die there are no comets seen;
> The heavens themselves blaze forth the death of princes."
> (*J. Cæsar*, II. 2).

It is Plutarch who is responsible for the tradition that a comet flamed in the sky when Brutus struck.

But you have heard enough now to show you how often Shakespeare drew upon the bank of the astronomical doctrines of his day to illustrate his thoughts and thus "to point the moral and adorn the tale." If he had lived in a later age he would have had more knowledge and could have made larger drafts upon a richer bank; for as science grows from more to more, its power to supply beautiful and effective illustrations grows too, and the true poet is able by his art, using it with a vaster horizon and upon a more diversified field, to delight the mind by conjuring up more beautiful fancies and weaving more complicated illusions. But with the knowledge of his day, nothing more entrancing could have been written, and no more potent spell could have been laid upon the mind than the poetry of this master poet of all the centuries. Where else can we find, from the pure stand-

point of poetry, anything to match Romeo's invocation to Juliet?

"Two of the fairest stars in all the heaven,
Having some business, do intreat her eyes
To twinkle in their spheres till they return.
What if her eyes were there, they in her head?
The brightness of her cheek would shame those stars,
As daylight doth a lamp; her eye in heaven
Would through the airy region stream so bright,
That birds would sing and think it were not night." (II. 2).

And again, Juliet, appealing to the imagery of the sky that is so fertile for lovers' fancies, exclaims—

"Come gentle night, come loving black-browed night,
Give me my Romeo; and, when he shall die,
Take him and cut him out in little stars,
And he will make the face of heaven so fine
That all the world will be in love with night." (III. 2).

Where, finally, in all literature, can we find the glories of the morning and the evening so beautifully balanced as in this description, in the *Sonnets*, of the eyes of his beloved?

"And truly not the morning sun of heaven
Better becomes the grey cheeks of the east,
Nor that full star that ushers in the even
Doth half that glory to the sober west,
As those two mourniug eyes become thy face." (*Sonnet 132*).

Anaximenes of Miletus fancied that the firmament was a rigid crystal vault, formed of glittering layers; the poet touches this with the wondrous alchemy of his art, and Lorenzo thus speaks to Jessica—

"Look how the floor of heaven
Is thick inlaid with patines of bright gold."
(*Merchant of Venice* V. 1)

And as twin to that figure, we have in *Hamlet* "This majestical roof fretted with golden fire."

Thus, it is, that the handiwork of the Omnipotent draws forth what is finest and best of thought and speech in man, and the everlasting starry firmament inspires and stirs up the poetic soul to its highest and noblest expression in "musical thought" or poetry, thus so tersely and gracefully defined by Thomas Carlyle.

STONYHURST COLLEGE OBSERVATORY, LANCASHIRE, ENGLAND.

By Rev. I. J. Kavanagh, S.J.

MY reason for selecting the Stonyhurst Observatory for my topic is largely a personal one, for I shall be talking about what is my own by many ties. The memory of pleasant years, of hard work done and of petty triumphs achieved, the memory of friends and their helping hands, are fair excuse for the personal note that may sound through my theme. Possibly this very thing may commend my effort to your kindly attention, for the whole world loves a lover. Besides it is encouraging to consider, in the case of the rise and growth of Stonyhurst Observatory, how small beginnings and patient work can culminate in deserved and gratifying success.

The Society of Jesus was early in the field of mathematical science, and, as far as circumstances have permitted, it has striven to maintain its traditions in this respect. Galileo counted the Fathers amongst his friends, and not the least among these was the great Jesuit Cardinal Bellarmine. The names of Boscovitch, Clovius, Hill, Kircher, Scheiner, Grimaldi, and, in our own day, de Vico Secchi and Perry have their place in the honorable annals of astronomy. Even now, in the midst of the strained conditions of the times, the Society counts 22 astronomical observatories, many of them splendidly equipped in men and instruments. Some have fallen from high estate. For instance, little has been done in Rome in recent years. The observatory and equipment that enabled Secchi to do such good work were taken from him and the Jesuits by the Piedmontese invaders. However, the work is started again and is now in the hands of Father Hagan, late of Georgetown Observatory, in Maryland. Elsewhere, as in Havana and Manila, the magnitude and economic importance of the meteorological results have masked the less brilliant but useful monotony of astronomical routine. A case in point is Father Algué's monumental work on the phenomena

of cyclones, just about to be published by the U. S. Government. Father Algué is Director of the Havana Observatory. Father Vinès, of Manila, on the theory of typhoons has been honored in the same way.

I might mention that both these men, as well as Secchi and one of the native Chinese Jesuits at Zi-ka-wei, and others, received a portion of their training at Stonyhurst Observatory, to which I beg to turn your kind attention. The story of Stonyhurst College goes back to the days when a Catholic College in England lay under the ban of a penal legislation. To meet these unfortunate conditions, the Jesuits founded in 1592, at St. Omer, a college for the education of English Catholic youth. In 1794, after many vicissitudes, the College faculty and the students came over to England, and settled down in Lancashire, on the old-time Sherbourne domain called Stonyhurst, which had been presented to them by one of the old boys, Sir Thomas Weld of Blundel Curiously enough, the Rector of the College, as lord of the manor, had the right of presentation to the neighboring Protestant parish of Mitton; a right, however, he never exercised.

Perforce the College made haste but slowly. It was only in 1838 that in the quaint old Dutch garden, in the midst of secular yew hedges, the second oldest and finest in all England, there arose the domed roof of the observatory. The principal instrument was a 12 cm. Jones equatorial. Twenty years after, at the instance and under the very friendly advice of Sir Edward Sabine, Father Weld purchased a set of magnetic instruments for eye observations. Thenceforward the record is unbroken. Shortly after, the Board of Trade selected Stonyhurst as one of its seven meteorological stations. Thereupon a full complement of apparatus was installed and the observatory was able to carry on its work with ease and efficiency. The new self-recording instruments for the photographic registration of the magnetic elements were installed in a many walled excavation, in which the equable temperature and the hygrometric conditions have proved most satisfactory, the latter being an important affair in rainy Lan-

cashire. The Mercury Barograph is also installed here. On the occasion of the British Association Meeting at Southport, in 1883 I think, a large party came up to Stonyhurst. Naturally a number of ladies and gentlemen went down to examine the magnetic installation, much to the confusion and consternation of the magnets. These timid creatures thereupon described such extraordinary and eccentric curves, that the graphs had to be rejected from the month's average, but are kept as curiosities. Had a dozen of the old Sherbourne Crusading Knights come up from their marble tombs in Mitton Church, clad in full armor, the behavior of the magnets had scarcely been worse. The arrival of a new 20 cm. equatorial by Carey made it necessary to build a dome some hundred yards away, where the heavy iron mounting would exert no disturbing effects on the magnets. The Jones equatorial was then also removed from the main octagonal building which was becoming inconveniently crowded. Two of the wings still shelter the meridian instruments and the sidereal clocks.

The normal, the wet, and dry bulb thermometers are photographically self-recording. I need no more than mention the anemograph which registers the velocity and direction of the wind by pencil tracings on a clock-driven cylinder. These registers are all the more valuable because the apparatus has never stopped since its first installation, a notable tribute to the maker and to the care of the assistants. Of course, there are also sunshine recorders and automatic registering rain guages. To those who know something of the Lancashire climate I need not suggest which of these two is the harder worked.

Besides the Jones, which is now given over to students' work, there is an 18 cm. Newtonian, a 24 cm. Cassegrain altazimuth, and a 12·5 cm. telescope by Clarke. Upon the death of Father Perry, who was for many years an esteemed and efficient Director, it was resolved by his many friends to set up a fitting monument to his memory. It was decided to erect a 38 cm. equatorial under a new dome. Fortunately the new instrument thus procured has proved equal to all expectations.

Some notes on the life of Father Perry, who did so much for Stonyhurst Observatory, may not come amiss, especially as some years back he came to this country and carried away, amongst other souvenirs, the pleasant remembrance of his visit to the Meteorological and Magnetic Observatory in the neighbourhood of Toronto, then, as now, under the very competent management of R. F. Stupart.

Stephen J. Perry was born in London in 1838 and went abroad for his education to the Benedictine College of Douai, where he remained seven years. He already manifested exceptional ability along scientific lines. Purposing to be a priest, he entered upon the study of philosophy in Rome at the English College. While here he resolved to seek admission to the Society of Jesus, being, as he says, largely influenced in this action by reading the life of the founder, St. Ignatius of Loyola. He was admitted to the Noviciate at Hodder House in England, and after the two years of probation required before anyone may take upon himself the obligations of the religious state, he took up his studies again, alternating with teaching, as is the custom of the Jesuits, till he had covered the usual 10 years of philosophy and theology preparatory to the priesthood.

Father Perry's mathematical talent was further developed under the teaching of such men as De Morgan in London and Cauchy, Delaunay, and Bertrand in Paris. Among his stories of these days was one about Bertrand, who was not noted for his neat blackboard work. One day he had to be replaced, on account of illness, by an assistant professor, a very competent man. The young professor, having expounded the matter clearly and neatly, had the mortification to see that many of his audience had left the hall. The truth is that these men had come from all parts of Europe to hear the great Bertrand and to note the unexpected and unprepared scintillations of genius, not to witness the commonplace proving of a proposition.

In 1868 he took up the Directorship of Stonyhurst Observatory with which he had had some connection at different times. He also did some teaching at the College. During the vacation

months he conducted magnetic surveys of Belgium and the various parts of France. These surveys furnished the first really satisfactory magnetic maps of these regions. He was attached to the Cadiz Eclipse parties in 1870, and was chief of four other Government Eclipse Expeditions. The last was to Isle du Salut off French Guiana (1889), where, through over exertion, he fell a victim to fever. The Jesuit missionaries at Georgetown, in Demerara, who were English, some of them old friends, had the melancholy consolation of giving him a last resting place. He had been in command of two Transit of Venus Expeditions: one to Kerguelen Island, the other to Madagascar. Father Perry was a good, organizer, a patient worker, an observer of the highest class, safe, cool, deliberate, ready for emergencies, most careful and foreseeing in his preparations, and dead sure of his results. He was, moreover, marvellously acute in their interpretation. However, he used to say that his colleague Father Walter Sidgreaves, the present director of the observatory, was the better observer, the best in England.

Though the study of colored and variable stars had been in vogue under Father Weld, the investigation of solar phenomena had not been neglected. Under Father Perry this latter received its greatest development. During all the twenty years of his directorship the drawings by projection of the Sun's surface, in general, and in detail, under low and high power, were made as often as possible. This work is done by W. McKeon, a lay brother of the order, a close observer, a skilful and conscientious draughtsman. Twenty years experience has rendered him exceptionally expert in *seeing* and *portraying* the delicate evanescent effects flitting, so to speak, over the paper. In case of a blurred, ill-defined, unseizable image, he tells me that a slight vibration given to the paper unravels, as it were, the jumbled details. It would appear a useful hint. I am convinced that the trained, discriminating eye can secure results far beyond the range of the dead, mechanical photographic lens. The Stonyhurst collection of solar drawings, executed with such accuracy and covering so long a time, has a high value, and, when placed

side by side with the contemporaneous magnetic records, throws suggestive lights upon the connection between magnetic and solar phenomena. Father Cortie of the observatory staff for some 16 years has written valuable papers in this relation and recently found himself crossing swords with Mr. A. W. Maunder of Greenwich.

Without in any way cutting in on solar work, under the present director, Father Walter Sidgreaves, Stonyhurst Observatory has done a great deal of stellar spectroscopic work. A Christie Hilger star spectroscope was purchased in 1883, but long before that a Troughton Sims instrument was in use for solar work, as was also a splendid Browing battery of 12 prisms, with a reversing prism, to be attached to the equatorial. Before Father Perry's time some special work had been done on the multiple and the colored stars, but it was he who gave the study of solar phenomena the greatest development. So that Father Sidgreaves' work was not a new departure but a mere natural development assiduously carried on. His studies of the Nova of Perseus and that of Auriga attracted much attention, while his monograph on *β Lyræ*, richly illustrated with spectrum photographs, is exhaustive. In this work he sometimes used the Hilger spectrograph with a fine Rowland grating (8 cm.) fed from a siderostat. The large equatorial, fitted with a Hilger poly-prism, is used for radiations less refrangible than the violet; for the violet and ultra-violet the 10 cm. Cross equatorial, fitted with a 22°·5 Thorpe prism, is brought into action. Father Sidgreaves finds that shorter exposure and results altogether satisfactory are achieved by doing away with the slit and running the star parallel to the refracting edge of the prism. Of course, this means very fine adjustment.

Besides the interest that attaches to the Observatory, there are also attractions for the lover of beautiful scenery and for the antiquarian. I sincerely hope that some of my readers may have an opportunity of realizing how well I am keeping within the bounds of strict truth in singing the praises of Stonyhurst in Lancashire.

Loyola College, Montreal.

THE STAR IMAGE IN SPECTROGRAPHIC WORK

By J. S. Plaskett.

THE object of this paper, the first part of which was read at a meeting of the Ottawa Section R. A. S. C., last winter, and which was published in the *Astrophysical Journal*, April, 1907, is to describe some experiments on the character of the star image given by the condensing system in use with the majority of star spectrographs—visual objective with auxiliary, photographic corrector. As is well known, the purpose of such a correcting lens is to change the form of color-curve of the objective, bringing $H\gamma$ instead of λ 5600 to a minimum focus, thus enabling a much greater length of star spectrum to be photographed at one exposure.

The objective of the Dominion Observatory is of 15 inches aperture, made by Brashear, while the original correcting lens has an aperture of 2¼ inches, and is placed some 32 inches within the focus. As will be seen later, the objective used visually is of the first quality, but when combined with the original corrector the resultant photographic image is not free from aberration. The causes leading to the discovery of this aberration, and to the present investigation, have been fully described in a previous paper* and it is not necessary to again dwell upon them, except to say that, although there was a great improvement in the performance after the inversion of one of the elements of the corrector as described in the paper just cited, photographic tests of the star focus for different temperatures indicated that the star spectrum was much wider than could be accounted for by atmospheric disturbances.

To determine whether a narrower spectrum could be obtained by a change in adjustment, a plate was made for each of six settings of the correcting lens, above and below its computed

*This Journal, Vol. 1, page 104, 1907.

position over a range of four inches. A simple device applied to one of the plate holders enabled ten successive star spectra to be made side by side on each of these plates at different settings of the slit position in the neighborhood of the star focus, the sixty spectra forming a record of the diameter of the star image under varying conditions. To ensure that the spectrum had not been widened by a drift of the star image along the slit, the spectroscope was turned in position angle until the slit jaws were parallel to an hour circle. By making the slit 0·2 mm. wide, and by using a bright star, *Vega*, a fully exposed linear spectrum was obtained in eight or ten seconds, evidently with no chance of widening due to drift. The width of the narrowest part of the narrowest spectrum on each plate, presumably where the star was in focus on the slit, was measured and these widths ranged from 0·085 to 0·115 mm. As the camera and collimator objectives are of the same focal length and as one second of arc in the focus of the refractor is equivalent to 0·0275 mm. the diameter of the star image according to this test must be between 3 and 4·5 seconds. The diameter of the central diffraction disc as given by the formula $d = 1{\cdot}2197\,\lambda/r$ is, for a 15-inch objective and H_γ light, about 0·57″ while the actual effective diameter as obtained from the width of star spectra is five to eight times as great.

This enlargement of the diffraction image may be due to three causes:—1. Aberrations in the spectroscope; 2. Atmospheric disturbances; 3. Aberrations in the system of objective and correcting lens.

1. *Aberrations in the Spectroscope.*—It is a simple matter to determine whether the wide star spectra obtained are due to this cause, for by direct photography of the star image no aberrations in the spectroscope can affect the result. A series of star trails was therefore made on ordinary plates by the system of objective and correcting-lens. A small plate, held in guides in the slit cap of the spectroscope, could be moved in these guides between exposures so as to make a number of trails on each plate. The collimator tube, carrying the plate with it, was moved by the

rack and pinion about a quarter of a millimeter between each exposure to ensure having one of the trails within ⅛ mm. of the focus. A plate each was made of six stars ranging from the third to the sixth magnitude, and the width of the narrowest trail on each plate, corresponding to the position where the star was most nearly in focus, was measured. Although the conditions of seeing both for trails and spectra were above the average, about 3 in a scale of 5, the trails were not continuous but broken and jagged, owing to atmospheric disturbances, and the measurements were made in two ways. First, of the width of narrow short parts of the trails where the seeing had been momentarily steady; and second, of the average width of a longer strip of trail. In the first series of measurements the widths varied from 0·070 mm. in the fainter stars to 0·110 mm. in the brighter stars, while the average widths of longer strips were about 20 per cent. greater. Since the widths of spectra were practically the same, it is evident that the cause must be sought in the star image itself, and is not due to aberrations in the spectroscope.

2. *Atmospheric disturbances.*—Newall in his paper on the design of spectrographs* has introduced a very useful conception, that of tremor discs, and he states that atmospheric disturbances enlarge the effective diameter of the star image. Such enlargement may be due either to bodily displacements of the image from its mean position or to the spreading out of the central image into a more or less expanded disc. He considers that the actual effect, so far as getting light through the slit of a spectrograph is concerned, is the same as if the image consisted of a central core from 1″ to 2″ diameter, surrounded by a more or less diffuse and gradually diminishing portion, the whole diameter being in the neighborhood of 4″ or 5″. If we accept Newall's estimates as correct, and if we remember that in no case was a sufficiently long exposure given to allow the outlying parts of the tremor disc to increase the width of spectrum or trail, then the diameter of the image given by the Ottawa objective and correcting lens, even allowing the extreme limit assigned by Newall

* *Monthly Notices*, LXV., p. 608, 1905.

for atmospheric disturbances, is nearly twice as great as it should be.

It is also a simple matter to test this conclusion experimentally. As the objective gives excellent visual definition it may be safely assumed that the visual star image is of normal diameter. A measurement of the width of spectra and trails produced by the visual image, and a comparison with the widths given by objective and correcting lens in photographic light should at once decide whether the observed effect is due to atmospheric tremor. The correcting lens was therefore removed, the spectroscope was adjusted for yellow light and spectra were made similarly to the previous ones, though on Cramer Isochromatic Plates, which have a pronounced band of sensitiveness almost identical in wave length with the turning point of the color curve of the objective. The widths of the spectra produced varied between 0·050 and 0·065 mm. about 2″, but, as the seeing was very unsteady, about 1½ in scale of 5, these widths are doubtless about 25 per cent. greater than would be the case with good seeing. For the star trails the same make of plate was used, light of shorter wave length than λ 5000 being absorbed by a yellow screen of plane glass placed in contact with the plate. Owing to the insensitiveness of the plate to light of wave lengths between λ 5000 and λ 5400, and to longer waves than λ 5800, only the light which is effective in forming the visual image can act in producing the trails. As before, the width of the trails varied with the brightness of the stars ranging from 0·025 mm. in faint trails to 0·055 mm. in stronger trails, or from 1 to 2 seconds of arc, while the average width over a longer strip of trail was about 20 per cent. greater. Notwithstanding the bad seeing both trails and spectra were much more sharply defined than those made with the correcting lens in photographic light and of only half the width.

These experiments conclusively prove that the abnormal width of spectra and trails in photographic light is not due to aberrations in the spectroscope nor to atmospheric disturbances, and clearly point to aberrations in the condensing system as the

cause of the observed effects. A short summary of the experimental data will render this more evident. The theoretical diameter of the central disc, or rather of the first dark ring for visual light λ 5600, is 0·74″; for photographic light λ 4340 is 0·54″. The actual width of visual spectra and trails is from 1″ to 2″ or one and one-half to three times the theoretical diameter.

Some further information regarding the size and character of the photographic image may be gained by considering its effective diameter under another aspect, that of the loss of light at the slit. Referring again to Newall's paper, and taking, as he does for an example, a tremor disc of 5″ diameter with a core 2″, we find that a slit 0·025 mm. wide will pass 35 per cent. of the incident star light; a slit 0·037 mm. 44 per cent.; a slit 0·05 mm. 58 per cent. and so on I am indebted to a suggestion by Professor Campbell for a method of testing this theoretical result experimentally. A series of star spectra were made at different slit widths and the resulting intensities compared. As it is practically impossible to make a number of wide spectra of uniform intensity throughout their width, photometric measurements can not be relied upon, and recourse must be had to visual estimates. Such estimates can be made more accurately if the exposures are so regulated as to give spectra of equal intensity, and, moreover, within the limits of exposure time and intensity used here, errors due to the characteristics of the plate employed are to a great extent avoided. The spectrum of *α Lyræ*, the star used, is practically continuous except for the *H* series and is therefore well suited for the estimation of intensities, while its brightness is such that only short exposures are required. Ten different slit widths between 0·012 and 0·25 mm. were used, and ten spectra; one through each slit opening, were made side by side on the same plate. The exposures were so regulated as to render the resulting spectra as nearly equally intense as possible, and the final estimate is the mean from a number of plates and from spectra of different widths. To render the comparisons more direct, slit widths will be represented by divisions, a single division corresponding to 0·025 mm., and the relative exposure times will

be reduced to a unit of 100 with a slit width of one division, 0·025 mm., or 0·91″, the normal width with the dispersion employed here.

TABLE I.

Loss of Light at Slit.

Slit Widths			Comaparative Times For Equal Intensity	
Divs.	Mm	Secs.	Experimental	Computed $\tau=5''$ $\gamma=2''$
0·5	0·012	0·45	300	
1	·025	0·91	100	100
1·5	·037	1·35	67	70
2	·050	1·82	50	54
3	·075	2·73	33	39
4	·100	3·64	28	34
5	·125	4·55	25	31
6	·150	5·45	21·7	31
8	·200	7·27	18·3	31
10	·250	9·07	16·7	31

The above table shows that the exposure required is inversely proportional to the slit width until this reaches 0·1 mm., leaving out of account widths less than a single division, where diffractional loss within the collimator plays an important part. It also shows that with normal slit width less than 17 per cent. of the light incident on the slit is transmitted. In Newall's hypothetical case 31 per cent. would be transmitted. The experimental data given above, using Newall's method of calculation, indicate a tremor disc 8″ or 10″ in diameter with a core about 3·5″ and, as the previous experiments have shown, this is much larger than can be accounted for by atmospheric disturbances.

3. *Aberrations in the system of objective and correcting lens.*—The above experiments point conclusively to aberrations in the system of objective and correcting-lens, when used with photographic light, as the cause of the observed effects but they give no information concerning the nature of these aberrations beyond indicating in a general way, from the appearance of out-of-focus photographs of spectra and trails, that spherical aberration is

present. It was decided, therefore, to make quantitative tests to ascertain if possible the nature and magnitude of the aberrations and the best means of removing them.

The most simple and accurate method of determining the zonal errors and axial astigmatism of a telescope objective is Hartmann's method* of extra-focal measurements. The principle of the method and the measurements and reductions necessary are extremely simple, while it gives accurate values with the expenditure of comparatively little time and without the use of appliances except such as can be readily made by anyone. For the benefit of those who have not the above paper at hand, and in order to render the present article complete, the essential principles of the method will be briefly described.

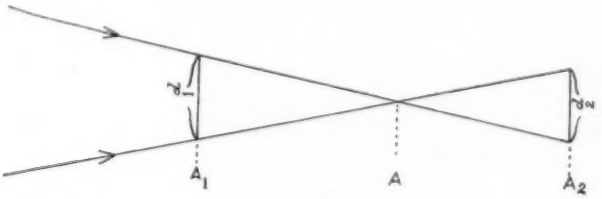

FIG. 1.

It depends upon the determination of the intersecting point of pencils of light coming from different parts of the objective. Suppose a diaphragm containing two small openings, equidistant from the centre and along a diameter, be placed over the objective. If the distance between the pencils of light coming from these openings be measured at two points, one within and one without the focus, the point of intersection of the pencils and consequently the focus for the particular zone in question can be at once obtained from similar triangles. For let d_1 Fig. 1, be the distance between the pencils at the scale reading A_1 within the focus, d_2 the distance at the scale reading A_2 beyond the focus. Evidently, then, the scale-reading for the focus $A = A_1 + \left[\frac{d_1}{d_1 + d_2}\right](A_2 - A_1)$. The distances d_1 and d_2 may be determined directly by micrometer

* *Zeitschrift für Instrumentenkunde*, 1904, pp. 1, 33, and 97.

measurements on the pencils from a star or distant artificial point source, or by making exposures on photographic plates in the two positions and measuring the distances between the resulting images by a measuring microscope. The latter method is preferable and was used exclusively, except that the visual determinations were checked by micrometer measures.

A zone plate *A* Fig. 2, similar to that described by Hartmann, was employed. The apertures, except the four inner ones, were each about 25 mm. in diameter and the radii of the nine zones were respectively 28, 47, 66, 85, 104, 123, 142, 160, and 178 mm. In order to determine the astigmatism along the axis, each pair of openings is duplicated by a second similar pair at right angles so that the focus of each zone of the objective is determined for two elements perpendicular to each other. In the case of the

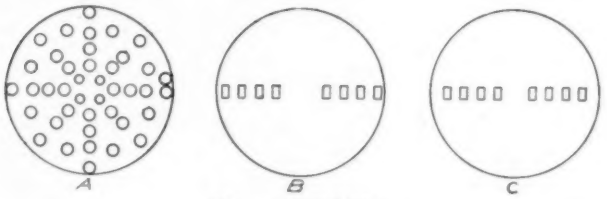

FIG. 2.—Zone Plates.

zone of 142 mm. radius the focus can be obtained for elements 45° apart. Thus an exposure within the focus, and a second one without the focus give data sufficient to determine the focus of each of nine zones of the objective in two directions perpendicular to each other. These two directions are distinguished from one another in the measurement by making an extra aperture in the zone plate, which, on being reproduced in the negatives, serves to identify the origin and direction of the angle φ.

To determine the zonal errors of objective and correcting lens, the zone plate was placed in position in front of the objective and a small photographic plate was placed in the guides in the slit cap of the spectroscope. The spectroscope is supported on two parallel tubes carried by an adapter on the eye end of the telescope, and can be readily moved up and down through a

range of about 20 cm. Experience showed that the images were most sharply defined, and the best measurements could be obtained when the plates were between 6 and 10 cm. from the focus. As the photographic focus was to be tested, an ordinary Seed 27 plate was first tried; but it was not found possible to make very accurate settings, as the pencils from the zone plate were spread out into radial spectra owing to the long range of wave length (λ 5000 to the limit passed by the object glass, say λ 3600) to which such a plate is sensitive. Several means of overcoming this difficulty were tried. As a yellow screen in front of an ordinary plate did not improve matters, the dispersion of the pencils must evidently be chiefly due to the light around H_β. An ordinary lantern plate, which is sensitive from about λ 4600 down, was therefore next tried and gave good images capable of accurate measurement, while if a yellow screen were used with such a plate the resultant images were again elongated, showing that the prolonged exposure entailed thereby had extended the action on the plate towards the red, and reintroduced the first difficulty. A yellow or red star was used in preference to a white or blue as limiting the action in the violet, shortening the effective range of spectrum, and thus giving images with less spectral dispersion with no apparent elongation.

Four sets of extra-focal plates were made which, on being measured, reduced, and the mean of the four taken, gave the focal positions of the nine zones, as tabulated below (Table II). All four measures are in substantial agreement, which of course is closer for the outer zones where the convergency of the pencils is greater. There the probable error of a single determination of the focus does not exceed 0·1 mm., while near the centre it may be as great as 0·5 mm. It will be noticed that the focus for the edge of the objective and correcting lens is upwards of 2 mm. longer than the focus near the centre, and if astigmatism be taken into account also, the difference is greater than 2·5 mm. The values are plotted graphically in the curve (A) of Fig. 3, the vertical distances being magnified some six or seven times, the appended scale representing millimetres. The horizontal line is

TABLE II.

ZONAL FOCI OF 15-INCH OBJECTIVE.

RADIUS OF ZONE	φ	OBJECTIVE AND CORRECTING LENS PHOTOGRAPH.C			OBJECTIVE ALONE VISUAL		
		Focus	Mean	Astigmat'm	Focus	Mean	Astigmat'm
28	45°	73·54		− 0·20	106·43		− 0·05
	135	73·94	73·74	+ ·20	106·54	106·48	+ ·06
47	0	74·19		+ ·08	108·35		+ ·42
	90	74·03	74·11	− ·08	107·51	107·93	− ·42
66	45	73·54		− ·30	106·67		− ·13
	135	74·14	73·84	+ ·30	106.93	106·80	+ ·13
85	0	74·15		+ ·11	106·42		+ ·26
	90	73·94	74·04	− ·10	105·91	106·16	− ·25
104	45	74·65		− ·23	106·15		− ·08
	135	75·11	74·88	+ ·23	106·31	106·23	+ ·08
123	0	75·68		+ ·22	106·20		+ ·09
	90	75·25	75·46	− ·21	106·02	106·11	− ·09
142	22·5	75·93		+ ·24	106.08		+ ·20
	67·5	75·32		− ·37	105·77		− ·11
	112·5	75·67		− ·02	105·82		− ·06
	157·5	75·83	75·69	+ ·14	105·83	105·88	− ·05
160	45	75·58		− ·15	105·91		+ ·04
	135	75·88	75·73	+ ·15	105·83	105·87	− ·04
178	0	76·11		+ ·21	105·93		− ·01
	90°	75·69	75·90	− ·21	105·95	105·94	+ ·01
Mean focus		75·34			106·01		

drawn in the position of focus that gives the smallest circles of confusion, in this case 0·04 mm. in diameter. The astigmatism will increase this to some extent so that probably the diameter will be nearly 2″. Unless the slit is set exactly at this mean position, which is not likely, the diameter of the confusion discs will be still further increased so that we may consider 2″ as a moderate estimate. It must be remembered, however, that, in speaking of circles of confusion, the conceptions of geometrical optics alone are being considered, and no account is taken of diffraction phenomena, which may have some effect on the geometrically calculated dimensions of the star disc resulting from aberrations of the magnitude here present. However, the experiments on the width of spectra and trails showed conclusively that the photographic image was about 2″ greater in diameter than the visual image, presumably unaffected by aberrations, and this agrees with the geometrical theory.

To determine where the aberrations arise it is necessary accurately to compare the performance of the objective used visually with the performance of the objective and correcting lens in the photographic part of the spectrum. Zonal tests were

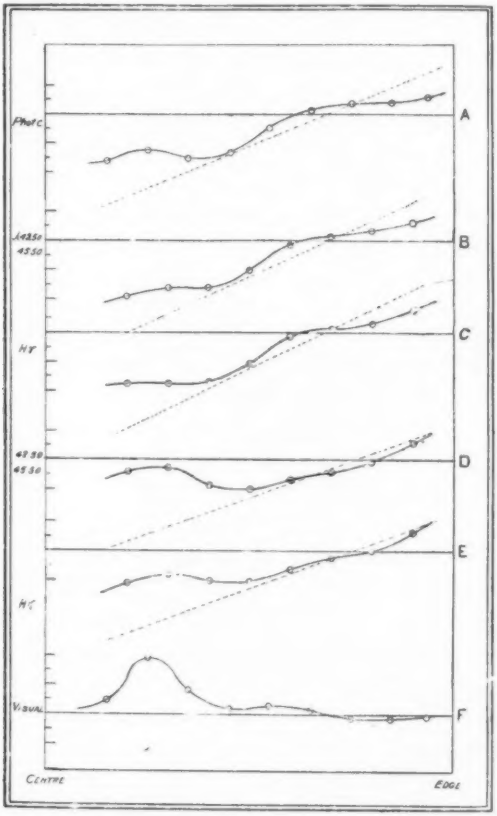

FIG. 3.—Zonal Differences in Focus.

therefore made of the objective alone. For this purpose the wave-length of the light used must be limited to λ 5400—λ 5800, the range to which the eye is most sensitive, which is the most

luminous in the spectrum, and which coincides with the turning point of the color curve of the objective. Fortunately, as the band of color-sensitiveness of Cramer Isochromatic plates almost exactly coincides with the same region, all that is necessary in order to obtain photographic test-plates is to absorb the blue and violet light by a suitable screen, and thus confine the action to the visual part of the spectrum. A deep yellow screen with plane parallel surfaces in contact with the plate was used. Although the pencils from the zone plate are displaced slightly on passing through this screen, these displacements are proportional, and the only effect will be to lengthen the focus for all the zones by the same amount, about one third the thickness of the screen, without in the least altering the relative positions of the pencils. An exposure of about a minute on *Capella*, through the screen, with the plate from 60 to 100 mm. from the focus, gives a negative of good intensity in which the images of the pencils are quite round, and free from any noticeable spectral elongation, thus allowing accurate measurement.

Five sets of extra-focal exposures were made in the visual part of the spectrum and the mean values resulting from the measurement and reduction of these plates are given in Table II and plotted graphically in curve F of Fig. 3. An examination of this curve shows that no point or focus is at a greater distance than 0·2 mm. from the position of mean focus, shown by the horizontal line, except a small region near the centre of the objective which has a longer focus. The effect of this region on the performance of the objective must, however, be exceedingly small owing to its small area, less than one-tenth of the objective, and to the weak convergency of the pencils proceeding from it. In fact, if Hartmann's criterion T* as to the quality of an objective be computed from the above mean values it is found to be 0·141. According to this classification an objective is moderately ("mässig") good when T is greater than 1·5, good when T is between 0·5 and 1·5, and exceedingly ("hervorragend") good

* *Zeitschrift für Instrumentenkunde*, 1904, p. 46.

when T is less than 0·5. In the ideal, absolutely zoneless objective T is 0.

Evidently the objective when used visually is of the very first quality, and the aberrations only appear when it is used in conjunction with an auxiliary corrector for spectrographic work. Whether the aberrations there present are due to the correcting lens, or to the objective when used in the photographic part of the spectrum remains to be determined. For this purpose a further application of Hartmann's method was necessary to find the color curves of the objective alone, and of the system of objective and correcting lens for a number of zones. It was hoped that such observations would throw light on the cause of the aberrations and suggest a possible remedy. They would also serve as a check upon the zone plate determinations, as, in this case, no spectral dispersion of the pencils could affect the accuracy of setting. To find such color-curves, the pencils of light coming from a zone plate fall on the spectroscope slit, and the distance between the resulting spectra taken with the slit within and beyond the focus gives a measure, calculated in the same way as before, of the focal position of any desired wave length for any particular zone.

It was decided to determine the color-curves of eight zones of 38, 57, 76, 95, 114, 133, 152, 171 mm. radius, and to prevent the spectra from merging into one another two zone plates were required, one (*B*) Fig. 2, of the four zones of 57, 95, 133, and 171 mm. radius and the other, (*C*) Fig. 2, of the remaining four. The central openings were each 20 mm. square and the outer 20 by 25 mm. The zone plates were so placed on the objective that the row of openings was parallel to an hour circle, and the spectroscope was turned in position angle until the slit was parallel to the openings, in order that irregularities in driving would not widen the spectra. To diminish the exposures as much as possible, bright stars, *Vega* and *Sirius* were used, and the slit was widely opened, as no inaccuracy would be thereby introduced in the distance between the spectra. The exposures were made

on a night when the temperature was nearly stationary, and were arranged in the following order:

Plate 1;	Zone Plate	(*B*)	Fig. 2;	slit about	50	mm.	within	the focus.
2;		(*C*)	" "		50	"	" "	"
3;		(*C*)	" "		40	"	beyond "	"
4;		(*B*)	" "		40	"	" "	"

This procedure was followed to avoid as far as possible any relative displacement of the focal determinations of the two sets, due to slight changes of temperature of the objective. That no measurable displacement has occurred is shown by the continuity of the zonal curves of Fig. 3 drawn from the combination of the two separate determinations, and by their agreement with those made by the regular zone-plate method.

Each of these plates contains eight spectra side by side, one from each light pencil transmitted by the zone plate, and the position of the focus for each zone, and for any desired wave-length in the range on the plate can be determined in exactly the same way as before. The hydrogen lines, in the first type stars used, serve as datum marks for the identification of wave-lengths, and measurements were made at eleven positions between λ 3970 and λ 5030. The corresponding focal points, as calculated from these measurements, are given in Table III for eight zones of the objective alone, and in Table IV for the same eight zones of the objective with correcting lens, the latter being about 40 mm. nearer the focus than its computed position.

The reason for using the correcting lens below its computed position at once appears on inspection of Fig. 4, which represents, in their correct relative positions, the color-curves of a median zone of 108 mm. radius, determined in exactly the same way as above. Curve *A* is the color-curve of the visual objective between the limits λ 6250 and λ 3970, which shows that the minimum focus is about λ 5600, exactly in its computed position. Curve *B* is the color-curve of the system of objective and correcting lens between λ 6250 and λ 3970, which shows that the minimum focus is about H_δ, instead of H_γ, its computed position. When the correcting lens is moved down, away from the objective, some

40 mm., we get curve *C*, and, at 70 mm., curve *D*. In curve *C* the minimum focus is nearly at H_γ and in *D* at λ 4460. Evidently the lowering of the correcting lens some 40 mm. effects considerable improvement in the color correction without, as the earlier experiments showed, appreciably enlarging the image, and the lens has been used in this position almost from the first.

TABLE III.

COLOR-CURVES OF OBJECTIVE ALONE

RADIUS OF ZONE	WAVE-LENGTHS										
	5030	$H\beta$ 4861	4680	4550	4040	$H\gamma$ 4340	4250	4175	$H\delta$ 4102	4035	$H\varepsilon$ 3970
38	85·57	86·87	89·64	92·02	94·28	96·30	90·78	102·48	105·82	109·59	110·91
57	85·30	86·30	88·95	92·00	94·28	96·60	100·25	102·74	105·95	108·75	111·66
76	83·84	85·78	88·76	91·09	93·67	96·39	99·50	102·34	105·31	108·69	112·31
95	84·67	85·42	88·41	90·82	93·56	96·34	99·37	102·61	105·68	109·11	112·12
114	84·38	85·78	88·68	91·16	93·87	96·77	99·58	103·06	106·19	109·63	112·65
133	84·71	85·93	88·68	91·08	93·91	97·16	100·21	103·16	106·72	110·11	113·08
152	85·06	86·29	89·18	91·49	94·41	97·42	100·53	103·71	106 79	110·10	113·38
171	85·41	86·87	89·65	92·03	95·02	98·04	101·29	104·62	107·81	111·10	114·53

TABLE IV.

COLOR-CURVES OF OBJECTIVE AND CORRECTING-LENS

RADIUS OF ZONE	WAVE-LENGTHS										
	5030	$H\beta$ 4861	4680	4550	4040	$H\gamma$ 4340	4250	4175	$H\delta$ 4102	4035	$H\varepsilon$ 3970
38	55·12	54·75	53·11	51·18	50·65	50·92	50·92	51·17	51·36	51·68	51·91
57	53·38	53·89	52·55	51·98	51·24	51·04	50·90	50·90	50·95	51·30	51·82
76	54·51	53·67	52·54	51·60	51·19	51·14	51·16	51·11	51·20	51·46	51·26
95	55·57	54·37	53·16	52·46	51·95	51·70	51·60	51·74	51·96	52·30	52·66
114	55·45	54·82	53·62	53·12	52·79	52·59	52·65	52·79	53·03	53·24	53·31
133	55·94	55·10	53·88	53·33	53·06	52·89	52·93	53·05	53·31	53·60	53·73
152	55·84	55·13	54·05	53·54	53·26	53·07	53·25	53·38	53·49	53·62	53·64
171	56·05	55·39	54·38	53·90	53·60	53·53	53·56	53·97	54·15	54·27	54·34

Although all the data in regard to the complete color-curves are given in Tables III and IV, still the actual curves drawn from these figures show all the conditions at a glance and are hence worth giving. To prevent too great a confusion of lines, the curves for four zones only, (Zone plate *B*, Fig. 1) of 57, 95, 133, 171 mm. radius, are shown here, Fig. 5, the upper curves being of objective alone, the lower of objective and corrector.

These curves show at a glance that, in the photographic part of the spectrum, the focus for the edge of the objective is longer than the focus for the centre, that it has negative spherical aberration. This chromatic difference of spherical aberration is

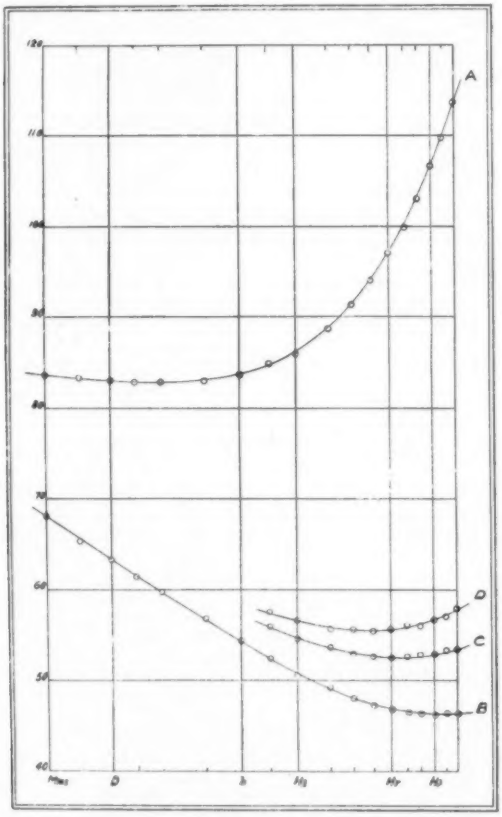

FIG. 4.—Color-Curves for a Median Zone.

inherent in two-part objectives of the ordinary glasses, and the only remedy is to compensate for it by introducing the correct amount of positive aberration by the correcting lens. How-

ever, the lower curves show that, instead of compensating for this chromatic difference, the correcting lens has, on the contrary, increased it somewhat and the focus for marginal rays is upwards of 2 mm. longer than the focus for central rays. This

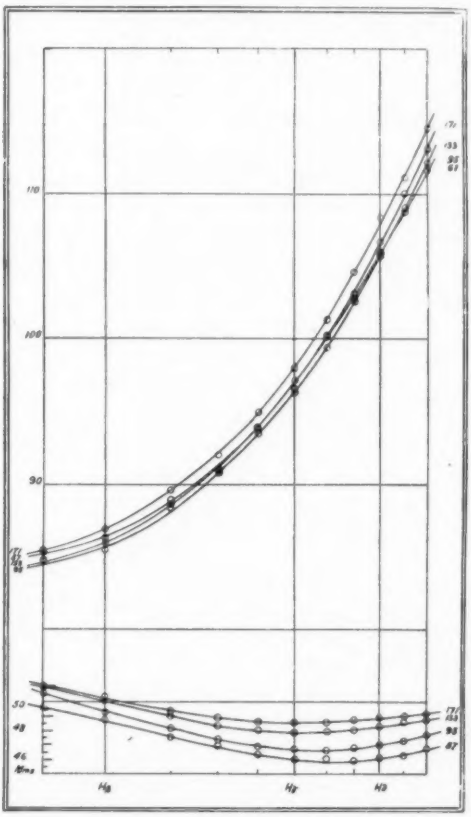

FIG. 5.—Color-Curves of Four Zones of Objectives and of Objectives with Corrector.

agrees almost exactly with the previous determination of the zonal foci of objective and corrector, and is good evidence of the substantial accuracy of the determinations. Before leaving these

curves it may be pointed out that, the crossing of the curve from the 57 mm. zone over the others, in passing from short to long waves, is due to the longer focus of the central zones in the visual part, and is further evidence in favor of the accuracy of the determinations.

To obtain a still more striking comparison of the cause and magnitude of the aberrations present in the system, the color-curves can be presented in another form, that of zonal foci curves like *A* and *F*, Fig. 3, previously determined. We have the color-curves, or the positions of focus, of the whole photographic region for eight zones of the objective in Tables III and IV, and these can be readily plotted in the same way and on the same scale as *A* and *F*, Fig. 3. If such curves were plotted for every wave-length in these tables they would show a striking agreement in form, but I have contented myself with representing the positions of the focus of eight zones for H_γ, the wave-length for which the system was computed, and for the mean of λ 4250, 4340, 4440 and 4550, the range of spectrum used here in velocity determinations. *E*, Fig. 3, is the curve of H_γ of the objective alone, *C* is the curve of H_γ of objective and corrector; *D* is the curve for λ 4250 to λ 4550 of the objective alone; *B* is the curve for λ 4250 to λ 4550 of the objective and corrector.

A comparison of curves *D* and *E* with *F* shows in a striking manner the chromatic differences of spherical aberration in the objective when used with photographic light. If we leave out of account or allow for the deviations in the central zones, we see that the focus of the outer is about 1·8 mm. longer than the focus for the central zones, a figure that agrees almost exactly with the computed difference as furnished me by Professer Hastings. A comparison of curves *A*, *B* and *C* with *D* and *E* shows that this difference, instead of being removed or diminished by the introduction of the correcting lens, has, on the contrary, been increased by about 0·6 mm. so that the difference in focus between outer and central zones is now about 2·5 mm., which, as before stated, will give a confusion disc nearly 2″ in diameter. I wish to point out, before leaving these curves, how the form of

the curve is maintained throughout from F up to A, except that the axis of the curve is inclined downward by the chromatic differences in the photographic region, and further tilted by the introduction of the correcting lens. To show this I have dotted in approximate positions of such axis in the curves E and A to correspond with the horizontal axis in F. It will be noticed that the irregularities in the visual curve are continued throughout, but in an intensified form, as is to be expected when it is considered that the objective was computed and figured for visual work, and its use in the photographic region with an auxiliary corrector was only a secondary consideration.

The above investigation shows that the Ottawa corrector fails to wholly fulfil the purpose for which it was intended. The question naturally arises, if the Ottawa corrector does not compensate for the chromatic difference of the Ottawa objective, how do other correctors perform? They were all, so far as I know, made on the same plan, having been computed and figured long after the objective had left the optician's hands. It seems to me quite possible and even probable that, in the major part, if not all of the telescopes employed in spectrographic work, aberrations of a similar nature and of a greater or less magnitude are present. If a correcting lens fails in one case, it is probable that other correcting lenses computed on the same principle will also fail. In the absence of definitive tests of their performance, the only means of judging is by a comparison of the relative exposure times required for different installations, taking into account size of object glass, slit width, and dispersion of the spectrograph. I am well aware that such a comparison must necessarily be incomplete and the results reached subject to an uncertainty say of 25 per cent. owing to the difficulty of comparing different installations under different conditions of seeing, etc. We have already seen how important a part is played by atmospheric disturbances in enlarging the star image so that the linear diameter of the image increases nearly in proportion with the focal length and therefore approximately, as the ratio of aperture to focal length does not vary much in large instruments,

with the diameter of the object glass. Consequently the effective value of increase of aperture is not proportional to the increase of area, but more nearly to the increase of diameter, which was accordingly used in the comparison. So far as regards the relative dispersion of different instruments, the exposure time was taken as directly proportional to the linear dispersion, presuming the same height of spectrum in each case. No account was taken of the difference in the loss due to absorption and reflection in the prism train, although this may be quite important in some cases. The exposure time required was taken as inversely proportional to the slit width, and this, as one of the experiments detailed above shows, is probably nearly in accordance with the facts. In Table V, following, data of the various equipments which are and have been used in radial velocity work so far as they were available to the writer, appear, but these data are incomplete* and may in some cases be in error, although probably not to a marked degree.

TABLE V.

COMPARISON OF EFFICIENCIES OF INSTALLATIONS

Equipment	Diameter of Objective, inches	Ratio of Diameters	Ratio of Areas	Linear Dispersion, Tenth-Meters per mm.	Slit Width, mm.	Theoretical Exposure	Actual Exposure Required		
							β Ophiuchi	*γ Aquilæ*	*α Boötis*
Ottawa	15	1	1	18·6	0·025	1	50 m	60 m	6 m
Yerkes	40	2·67	7·1	10·8	·038	0·42	75	115	15
Lick	36	2·4	5·76	12·5	·025	0·62	25?	25?	4?
Lowell	24	1·6	2·56	11·4	·025	1·02	120	120	20?
Newall	25	1·67	2·78	14·6	·025	0·76	70	75	15
Bonn	12	0·8	0·64	15·2	·020	1·91	75	75	15
Pulkowa	30	2·0	4·0	13·0	·020	0·89	65?	65	15
Lord	12·5	0·83	0·69	18·6	·025	1·20	60?	60?	4

* Since writing the above, Mr. V. M. Slipher, of Lowell Observatory, informs me that the exposure times given in Table V for their equipment are too large. These were taken from his results on Standard Velocity stars, but Mr. Slipher states that the early plates were not only over-exposed, but the star spectrum was made wider than necessary. Under such conditions the Lowell equipment would make a much more favorable showing.

The above comparison shows that the Lick, Bonn, and Lord equipments *in practice* approach more nearly the theoretical efficiency than the Ottawa, but the Yerkes, Lowell, Newall, and Pulkowa depart farther from it.

If the Ottawa equipment can be made more efficient, and if its range can be increased by an improvement in the quality of the image given by its condensing system, by the introduction of a new correcting lens, it is therefore probable, from the above comparison, that a similar improvement may be effected in the majority, if not all, of the above cited installations. Such an improvement would be worth considerable effort, and on the completion of the above experiments, and on obtaining quantitative values of the aberration of the correcting lens, I immediately communicated the data to the John A. Brashear Co. and to Professor Hastings, with a request to use their combined efforts towards supplying a new correcting lens free from such defects. With their well known willingness, I may say eagerness, to spare neither trouble nor expense in producing the highest quality of optical work, the Brashear Co. readily undertook to make a new correcting lens to computations by Professor Hastings, to whom I am very much indebted, not only for his interest in, and most careful treatment of the problem, but also for many useful criticisms and suggestions on the present paper. Professor Hastings finds a very marked agreement between his computed data of the objective, the color-curves and chromatic differences, and my observations. He explains the failure of the correcting lens to compensate for the chromatic differences of focus, which it was computed to do, by the fact that this lens has to correct the errors of an objective of nearly fifty times the area, that the small departure of the wave surfaces from a true sphere have grown enormously when they have reached the corrector, and that a perfect correction by spherical surfaces can hardly be hoped for. As a matter of fact the new lens was only finally corrected by departing from the spherical form.

After much careful study by Professor Hastings, the free aperture of the new corrector was fixed at 4 inches, while its

effective aperture, or the diameter of the cone of rays intercepted was made 3·8 inches, and its position is therefore 57 inches within the focus. The curves were so computed by Professor Hastings that, with truly spherical surfaces of the given radius, when used in conjunction with the objective, the system would be free from aberration at $H\gamma$. This was done to obviate the necessity of sending the 15-inch objective to Allegheny, as the spherical surfaces can be tested by interference. The corrector could not be tested in the ordinary way by the Foucault test, not only bacause it must have a certain amount of positive aberration, but also because it acts almost like a plate and cannot form any image.

The Brashear Co. completed the lens in a very short time after receiving the computations from Professor Hastings, and it was promptly sent to us. Owing to the great distance, nearly five feet, that it requires to be placed within the focus, a new method of mounting had to be devised and constructed. If it were mouuted in a 4-inch tube, supported at the lower end only, it would not remain collimated in different positions of the telescope. The upper end of the tube holding the corrector was therefore made to slide into a ring which was attached to the telescope tube by three equidistant radial rods with nuts on the outside of the tube. This ring could be adjusted to any position, at or near the axis of the tube by means of these nuts, and it was made exactly central in the following way. The corrector was removed from its cell and a thin plate of sheet metal with a central hole about ⅛-inch diameter inserted in its place. The collimator was removed and two similar plates inserted at the upper and lower ends of the central tube of the spectrograph. Finally the main objective was also removed and a board inserted having a minute hole exactly in the centre of the cell. Through these holes fine piano wire was threaded. When the telescope was pointed to the zenith, the upper end of the wire fastened and a weight attached to the lower end, the collimation could be exactly adjusted. The eye can easily judge very closely when the wire is central in ⅛-inch holes, the upper one being observed

by the bent guiding telescope. By this means the collimation of the corrector, and also at the same time, of spectrograph was correctly adjusted to within 0·01 inch and the fixed position of the guiding ring ensured that the corrector would always return to the same position. Flexure of the telescope tube will change this collimation slightly, not sufficiently, however, to have any effect on the image, but this cannot be guarded against in any case, on account of its variation in magnitude and direction.

TABLE VI.

ZONAL FOCI OF OBJECTIVE AND NEW CORRECTOR

RADIUS OF ZONE	φ	NEW CORRECTING LENS			NEW CORRECTING LENS REFIGURED		
		Focus	Mean	Astigmat'm	Focus	Mean	Astigmat'm
28	45°	91·07		+ 0·26	91·90		+ 0·28
"	135	90·55	90·81	− ·26	91·34	91·62	− ·28
47	0	91·55		+ ·13	91·97		− ·06
"	90	91·30	91·42	− ·13	92·08	92·03	+ ·05
66	45	91·04		+ ·22	91·51		+ ·23
"	135	90·60	90·82	− ·22	91·04	91·28	− ·24
85	0	90·66		+ ·07	90·57		+ ·00
"	90	90·53	90·59	− ·07	90·56	90·57	− ·01
104	45	91·01		+ ·30	90·64		+ ·12
"	135	90·41	90·71	− ·30	90·39	90·52	− ·13
123	0	91·14		+ ·12	90·54		+ ·08
"	90	90·90	91·02	− ·12	90·39	90·46	− ·07
142	22·5	91·28		+ ·03	90·52		+ ·09
"	67·5	91·41		+ ·16	90·42		− ·01
"	112·5	90·94		− ·31	90·26		− ·17
"	157·5	91·36	91·25	+ ·11	90·53	90·43	+ ·10
160	45	91·85		+ ·25	90·40		+ ·07
"	135	91·36	91·60	− ·24	90·26	90·33	− ·07
178	0	92·43		+ ·15	90·60		+ ·33
"	90°	92·14	92·28	− ·14	89·95	90·28	− ·33

A visual examination of the illumination of the collimator and camera objectives by star light showed some Improvement over the old corrector, but indicated that the aberration was not entirely removed. As soon as possible a test of the zonal differences of focus by Hartmann's method was obtained, and the mean of four sets is given in Table VI., while the results are plotted in Fig. 6, curve *B*. For comparison, curve *D* is of the objective alone in visual light, and curve *A* of the old corrector. The

Table and curve show that there is still a difference in the focus of centre and edge of about 1·5 mm., while with the old corrector it was nearly 2·5 mm. Notwithstanding this improvement it is doubtful if in practice the new corrector would give much better results than the old owing to the steeper form of the curve near the edge. It had, however, this advantage, that it would much

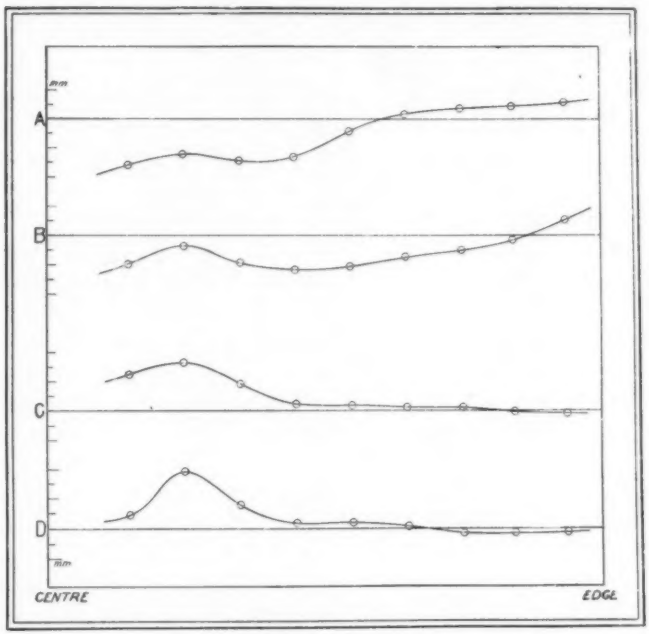

FIG. 6.—Zonal Differences of Focus.

more readily lend itself to refiguring than the original lens owing to the regular increase of the aberration from a median zone to the edge.

The reason for the non-fulfilment of the computed results must in all probability be looked for in the small unavoidable deviations from the computed values in thickness and radius of curvature, and in very small departures from truly spherical sur-

faces, which in combination may account for the observed aberration. This serves to show the necessity of some direct method of testing the aberration in such cases. It would undoubtedly be most satisfactory to test the corrector with the objective with which it is to be used, but as this was not practicable in the present case, some other means had to be devised. Mr. McDowell informed me in the correspondence on the subject that if he knew the exact amount of change of focus required for the different zones, he was certain he could easily figure the lens to suit. In consequence, after a second confirmatory Hartmann test, and by the kindness of the Director, Dr. W. F. King, I took the corrector to Allegheny to have it refigured, being prepared to make there the necessary tests by the Hartmann method in addition to Mr. McDowell's tests.

After a trial of a method of testing at the centre of curvature of a spherical mirror and a discussion of two or three alternative proposals, the following method of obtaining the aberration of the corrector was devised. An artificial star was placed at the principal focus of a 6-inch objective and the resulting parallel beam was incident upon and rendered convergent by a 4-inch objective of 60 inches focus. The corrector was placed 3 inches beyond and consequently 57 inches from the focus, and intercepted a cone of light of the same diameter and angular aperture as when used with the 15-inch objective. The aberration could then be easily tested at the focus by the Foucault method or by the extra-focal exposures of the Hartmann method. Both methods showed the focus of the edge rays to be about 0·7 mm. shorter than the focus of the central rays.

As the previous tests of the corrector had shown that its edge focus required shortening by about 1·5 mm. it must consequently be figured to give about 2·2 mm. of positive aberration. The first test after a few minutes polishing of the outer concave surface showed aberration of nearly 4 mm. Mr. McDowell's remarkable skill in figuring surfaces enabled him, at the second trial, to get the difference between centre and edge focus so near the required 2·2 mm. that the deviation, after several careful

measures by different individuals, was not determinable. As a Hartmann test confirmed the figures the corrector was considered completed. The actual time spent in polishing did not exceed fifteen minutes, although the preparation and the various tests occupied about two days. I can hardly speak in high enough terms of the way the John A. Brashear Co. have treated us in the matter of this correcting lens, and indeed in all other work they have done for us. Their aim is evidently to produce only the best, and to spare neither trouble or expense so long as any chance of improvement exists.

A final set of extra-focal exposures of the refigured corrector gave the differences of focus shown in Table VI., and indicated graphically in curve *C* of Fig. 6. Except for the deviation in the central zones, which is of no practical importance owing to the small relative area and to the narrow convergency of the pencils and which, as the visual curve indicates, probably arises in the objective, the deviations from the mean focus are less than with the objective alone. Although this remarkable result, so far as the smoothing out of the visual curve is concerned, has a certain element of chance in it, there is no doubt that given careful measurements of the required change, the Brashear Co. can produce it to a very close degree of approximation, and, in this way, a practically perfect corrector may be obtained without sending the objective to the optician.

No comparative tests of the exposure times required, of the width of spectra or trails, nor any determination of the color-curves have yet been made. When all the tests have been completed the results may be published later. There is no doubt in my mind that the exposure time will be considerably diminished and the chance of systematic error much decreased by the marked improvement in the character of the star image.

I cannot close without expressing my indebtedness to the Director, Dr. W. F. King, for the encouragement and help he has given me throughout, and for his willingness to meet all needs that have arisen, not alone in this, but in every other case.

MEETINGS OF THE SOCIETY

AT TORONTO.

June 18, 1907.—An open air meeting of the Society was held on the University lawn adjoining the Meteorological Observatory, and as the evening was fine a large number were present. With the Society's telescopes and the six-inch refractor of the Observatory excellent views of the Moon and other celestial objects were obtained.

September 17.—Mr. A. F. Miller described his observations of the planet Mars, made with his 4-inch refractor during the recent opposition. Having carefully studied the maps of Mars and familiarized himself with its markings, he scrutinized it on every favorble occasion and was able to see many of the markings hitherto reported as seen only with larger instruments. (A fuller account will appear in the next number of the JOURNAL).

The paper of the evening was by Mr. W. Balfour Musson, on "Some Notes on the Nebular Theory." Barnard's recent photographs of nebulæ and his statements that they were contradictory to the nebular hypothesis were considered. Photographs of various nebulæ in possession of the Society were exhibited on the screen, and the conclusion was drawn that nothing in them was inconsistent with the theory.

October 1.—The following were elected members of the Society :

A. R. Hassard, B.C.L., 9 North St., Toronto.
W. J. Wintemberg, 23 North St., Toronto.
John S. Martin, Deer Park, Ont.
Sidney Silcox, B.A., D. PAED., 192 Jarvis St., Toronto.
Henry C. McLean, 2 Wellington St., Brantford.

Professor Hirayama, of the Astronomical Observatory, Tokyo, Japan, was elected a Corresponding Fellow.

Two papers were contributed during the evening. The first was by Mr. J. Frederick Sharpe. It was a continuation of his paper given some months ago upon the subject of the Great Pyramid, and treated especially of the interior of the Pyramid. Mr. Sharpe's account was founded principally upon that of the late Piazzi Smyth, and in general followed his theories. Mr. Sharpe's paper was followed by an interesting discussion in which Messrs. Paterson, Elvins and J. G. Ridout took part. The second paper was by Mrs. Flora McD. Denison, and consisted of a description of a remarkable sunset which she had witnessed during the last summer on Lake Massanoga. Mrs. Denison's paper was followed by a description by Dr. Chant of marvellous changes in the form of the Sun as seen at sunset from Lick Observatory. In the five minutes before the disappearance of the Sun it assumes many extraordinary shapes, due undoubtedly to refraction through the layers of atmosphere of varying density. Sketches of some of the forms were shown on the blackboard. (See Frontispiece).

October 15.—A telegram was read from Harvard College Observatory announcing the discovery by Mellish at Madison, Wis., of a comet on Oct. 13.9 G. M. T. in position, R. A. $8^h\ 31^m$, Decl. $-9°\ 24'$. Magnitude 8, motion slow northwest.

In a letter Mr. A. F. Miller reported that *o Ceti* is now visible to the naked eye, appearing of the fifth magnitude on the 5th instant. It was also stated, on the authority of the Director of the Harvard College Observatory, that the maximum of the star may be expected about November 15.

Mr. Andrew Elvins drew attention to the fact that the Sun (at the time of the meeting) had three large groups of spots, and expressed surprise that so much activity should be exhibited at a time so far removed from a sun-spot maximum.

Mr. Collins drew attention to a paper in the *Monthly Notices* by Barnard, in which a recent photograph of the "Owl" Nebula was compared with drawings made some years ago. There is evidence of some change having taken place in the interval.

A set of six lantern slides made from photographs of the partial eclipse of the Moon on July 24 last, taken by Rev. Dr. Marsh, of Springville, were presented to the Society and exhibited on the screen. The large audience present expressed pleasure with the photographs.

The lecture was given by the President and consisted of an account of his recent experiences at the Lick Observatory. By means of many lantern slides Dr. Chant described his trip to Mt. Hamilton, the views about it and the working of the observatory. He arrived on June 11 and remained until August 27. Some account of the work carried on in the observatory was given.

ASTRONOMICAL NOTES.

The "Crocker" Eclipse Expedition from the Lick Observatory and a Smithsonian Institution Expedition will be conveyed by the U. S. gunboat *Annapolis* to view the total eclipse of the Sun on January 3rd, next, at Flint Island in Central Pacific Ocean, longitude 151° 48′ and latitude 11° 26′ S. The expedition will sail from San Francisco on November 22nd and expects to return on January 25th. F. R. McLean, of Tunbridge Wells, England, has also chartered a vessel to carry an English expedition to the same place. "Totality" will last $4^m\ 6^s$, beginning at $11^h\ 18^m$ local mean time, with the Sun 15° from the zenith, in good position for observation.

The presidential address of Sir David Gill before the British Association for the Advancement of Science at Leicester, is of unusual interest from an astronomical standpoint. It is printed in full in *Science* for August 16th and should be read by everyone interested in a philosophical treatment of astronomical problems.

It is with profound regret that we notice the death, on August 13th, last, of Professor Hermann Carl Vogel, Director of the Potsdam Astrophysical Observatory, in his 66th year. Dr. Vogel has for many years been an Honorary Fellow of this Society. An extended notice of his work will appear in our next issue.

We regret also to note the death of J. G. Petrie, F.R.A.S., late secretary of the British Astronomical Association.

Under date of October 28th, Harvard College Observatory Astronomical Bulletin announces "A telegram has been received at this observatory from Professor W. W. Campbell, Director of the Lick Observatory, stating that prominent bright knots have been visible during the past week in Saturn's rings, two east, two west, symetrically placed."

On November 14th the planet Mercury will transit the northern portion of the Sun's disc. The times of contact, computed below, are for 75th meridian time.

	h	m	s
Ingress, exterior contact, November 14	7	23	40
Ingress, interior contact	7	26	19
Least distance of centres, 12′ 38″.4	8	6	48
Egress, interior contact	9	47	18
Egress, exterior contact	9	49	58

Mellish's Comet, 1907 *e*.

The elements and ephemeris of Mellish's comet, 1907 *e*, have been calculated by Miss Lamson, at Washington, D. C., and by Crawford, Glancy and Morgan at Berkeley, Cal., from observations made on October 15, 16, 17.

Elements.

		Berkeley	Washington
Time of passing perihelion,	T =	Sept. 16.13	Sept. 12.47 G.M.T.
Perihelion minus node,	ω =	296° 46′	291° 42′
Longitude of node,	Ω =	53 36	55 32
Inclination,	i =	120 12	118 53
Perihelion distance,	q	0·987	0·973

G.M.T.	Ephemeris (Washington)		Light
1907, Oct. 19.5	R.A. 8h 14m 04s	Decl. −7° 06′	1·15
" 23·5	7 57 41	−4 38	
" 27·5	7 36 01	−1 30	
" 31·5	7 06 49	+2 39	2·06

RECENT SEISMOGRAPHIC RECORDS.

TORONTO OBSERVATORY, 1907.

THE following is a list of earth tremors recorded both at Toronto and Victoria, B. C., during the months of August, September and up to 21st October, record for the latter date not having been yet received. Times given are Greenwich mean time.

VICTORIA, B. C.

Dates.—August 5th, 8th, 11th, 13th, 17th, 22nd, 29th. September 1st, 2nd, 23rd, 25th. October 11th, 16th, 17th.

TORONTO.

Dates.—August 5th, 8th, 11th, 13th, 17th, 22nd. September 2nd, 23rd. October 16th, 17th, and 21st. With the exception of September 2nd and 23rd and October 16th and 21st, the records show but a slight thickening of the line and were unimportant. The following are the times of the important ones:

VICTORIA, B.C.

Date	Preliminary tremors	Large waves	Max.	Ending	Amplitude
	h m	h m			
Sept. 2nd	16 10·1	16 18·2	16 29·3	18 53·4	13·2 mm.
" 23rd	21 41·5	21 54·4	21 56·1	22 56	2·5 "
Oct. 16th	14 1·6	14 8·8	14 11·4	16 39·5	over 20 mm. very large

TORONTO.

Sept. 2nd	16 14·3	{16 33·5 / 16 21·6}	16 43·4	19 27·3	13·8 mm.
" 23rd	21 52·3	21 58·9	16 59·3	22 55	about 1·5 "
Oct. 16th	14 4·8	14 13·3	14 18·5	16 4·5	over 20 mm.
" 21st	Air Curr. marked	5 25·0	5 27·6	Air C.	2·0

The disturbance on the 2nd September originated in the vicinity of the Aleutian Islands; that on the 23rd at Guatemala, many houses and churches being damaged. The very large disturbance of the 16th October had its origin in the vicinity of the Friendly Islands, South Pacific, and was apparently of submarine origin. The disturbance of October 23rd was in Central Asia, being of a very destructive character, a large loss of life and property being reported.

SUMMARY REPORT OF THE WEATHER IN CANADA, AUGUST 1907.

TEMPERATURE—The temperature was just the average in a few isolated localities, chiefly in Manitoba and Eastern Quebec, otherwise throughout the Dominion it was below the average, the negative departure varying from 1 to 3 degrees, except in Alberta, where it was 5 degrees, and in Northern British Columbia 7 degrees.

The following are the highest and lowest temperatures recorded at various stations :—

British Columbia.—Dawson City, 78, 30 ; Atlin, 71, 34 ; Port Simpson, 71, 44 ; Victoria, 78, 44 ; New Westminster, 89, 44 ; Barkerville, 80, 28 ; Kamloops, 95, 46 ; Vancouver, 80, 42 ; Duncans, 88, 39 ; Agassiz, 96, 40.

Western Provinces.—Edmonton, 84, 30; Battleford, 84, 36 ; Prince Albert, 80, 38 ; Calgary, 81, 30; Medicine Hat, 91, 36 ; Swift Current, 94, 36 ; Regina, 87, 32 ; Minnedosa, 79, 34 ; Winnipeg, 85, 38 ; Portage la Prairie, 82, 41.

Ontario.—Port Arthur, 83, 38 ; White River, 76, 30 ; Southampton, 88, 39 ; Parry Sound, 90, 42 ; Port Stanley, 82, 43 ; Toronto, 87, 48 ; Kingston, 81, 42 ; Rockcliffe, 85, 35 ; Ottawa, 89, 47 ; Beatrice, 86, 36 ; Stony Creek, 94, 43 ; Uxbridge, 88, 40 ; Meaford, 84, 44 ; Peterborough, 89, 41 ; Port Burwell, 81, 41 ; Paris, 88, 42 ; Port Dover, 88, 44 ; Lucknow, 88, 35 ; Huntsville, 85, 41 ; Welland, 88, 48 ; Sutton West, 92, 46 ; Bruce Mines, 79, 37 ; Agincourt, 90, 45 ; Copper Cliff, 87, 42 ; Brantford, 90, 41 ; Hamilton, 91, 48 ; Bancroft, 90, 36; Haliburton, 90, 33 ; Otonabee, 88, 48 ; Cottam, 88, 40 ; Bala, 88, 42 ; Stratford, 86, 41 ; Chatham, 90, 45 ; Clinton, 88, 36.

Quebec.—Montreal, 88, 50; Quebec, 84, 43 ; Father Point, 78, 44.

Maritime Provinces.—Charlottetown, 77, 47; Chatham, 87, 44; Sydney, 78, 36; Halifax, 78, 46; Yarmouth, 73, 42; St. John, 73, 50; Sussex, 80, 36; St. Stephen, 85, 37; Summerside, 75, 46; Dalhousie, 79, 40; St. Stephen, 85, 41; Port Hastings, 78, 49.

PRECIPITATION.—In the southern portions of Vancouver Island and on the Lower Mainland the rainfall was very light, less than half the average amount in many localities. In other parts of British Columbia it was nearly everywhere much in excess of the average, Cariboo recording nearly three times the usual quantity. In the Western Provinces and east as far as Lake Superior, with the exception of a few localities in Southern Alberta, the rainfall was also remarkably heavy, the positive departures being equivalent to over 100 per cent. at Edmonton, Swift Current and Regina; 52 per cent. at Prince Albert, 57 per cent. at Minnedosa, and 89 per cent. at Port Arthur. The Peninsula of Ontario and the Ottawa and Upper St. Lawrence Valleys, on the other hand, suffered from the lack of rain, the drought being severely felt in nearly all districts, the deficiency of rainfall varying from 50 to 76 per cent. In the western portion of the Province of Quebec the rainfall was also exceedingly light, but eastward it increased steadily, reaching the average amount a little below Quebec City and exceeding it by from 18 to 28 per cent. in the Gaspé Peninsula; much rain also fell over the Maritime Provinces, the excess from the usual quantity varying from 3 per cent. in Prince Edward Island, to 36 and 38 per cent. in parts of Nova Scotia.

SEPTEMBER, 1907.

TEMPERATURE.—In British Columbia, exclusive of Cariboo, the temperature was above the average by from 1 to 3 degrees. In the Peninsula of Ontario it was also above the average by an equal amount, but over the large remaining portion of the Dominion a negative departure occurred, except in one or two isolated localities where the average was just maintained. The

chief negative departure, amounting to 3 degrees, was experienced in Saskatchewan and Alberta, elsewhere the departure was usually from 1 to 2 degrees.

The following are the highest and lowest temperatures recorded at various stations :—

British Columbia.—Dawson City, 66, 24 ; Atlin, 65, 26 ; Pt. Simpson, 69, 38 ; Victoria, 85, 40 ; New Westminster, 82, 39 ; Barkerville, 66, 22 ; Kamloops, 84, 41 ; Vancouver, 81, 41 ; Rossland, 73, 32 ; Agassiz, 86, 36.

Western Provinces. Edmonton, 78, 26 ; Battleford, 81, 20 ; Prince Albert, 74, 20 ; Calgary, 80, 20 ; Medicine Hat, 91, 24 ; Swift Current, 80, 20 ; Regina, 77, 14 ; Minnedosa, 76, 20 ; Winnipeg, 77, 22, Portage la Prairie, 77, 27.

Ontario.—Port Arthur, 71, 23 ; White River, 70, 18 ; Southampton, 81, 40 ; Parry Sound, 84, 34 ; Port Stanley 76, 41 ; Toronto, 83, 40 ; Kingston, 75, 37 ; Rockcliffe, 80, 30 ; Ottawa, 81, 36 ; Brantford 85, 32 ; Clinton, 84, 37 ; Peterborough, 84, 36 ; Port Dover, 79, 42 ; Lucknow, 82, 30 ; Bancroft, 81, 27 ; Port Burwell, 77, 42 ; Sutton West, 85, 30 ; Bruce Mines, 80, 28 ; Paris, 84, 39 ; Owen Sound, 84, 37 ; Uxbridge, 82, 37 ; Stony Creek, 89, 39 ; Haliburton, 80, 33 ; Sarnia, 83, 32 ; Otonabee, 82, 40 ; Meaford, 83, 38 ; Stratford, 81, 34 ; Welland, 83, 43.

Quebec.—Montreal, 88, 39 ; Quebec, 74, 29 ; Father Point, 70, 28 ; Brome, 79, 31 ; Sherbrooke, 80, 31.

Maritime Provinces.—Charlottetown, 72, 30 ; Chatham, 78, 30 ; Sydney, 76, 32 ; Halifax, 77, 34 ; Yarmouth, 72, 37 , St. John, 69, 39 ; St. Stephen, 79, 29 ; Fredericton, 78, 31.

PRECIPITATION.—In British Columbia at Victoria, on Vancouver Island, the rainfall was 45 per cent. below the usual amount, but on the mainland it was above the average, the excess varying from 3 per cent. in Cariboo to 100 per cent. in more southern districts. In the Western Provinces Calgary recorded an excess of precipitation of over 100 per cent., but all other localities gave a deficiency ranging from 8 per cent. at Battleford to 47 per cent. at Swift Current, and 67 per cent. at

Winnipeg. In Ontario, at Parry Sound, the rainfall was 29 per cent. less than the usual amount and at Southampton it was the average, but all other localities recorded a positive departure, which in several districts was as much as from 60 to 80 per cent. In Quebec the rainfall was above the average and nearly everywhere by about 25 per cent. In the Maritime Provinces, Sydney recorded a deficiency of 35 per cent., whilst elsewhere there was a positive departure, the chief departures being St. John, 41 per cent., Chatham, 48 per cent., and Fredericton 59 per cent.

METEOROLOGICAL OFFICE,
TORONTO,
OCTOBER 26, 1907.

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